ANCIENT EGYPTIAN METALLURGY.

[*Frontispiece.*

MAJOR H. GARLAND

was, before the War, Superintendent of Laboratories at the "Citadel," Cairo.

The first year of the war he invented, and superintended, the manufacture of the "Garland" grenade, sending 174,000 to the Dardanelles and Gallipoli.

In October, 1916, he left Cairo for Arabia, where he trekked in the desert disguised as an Arab, destroying the Turkish Railway. He was awarded the O.B.E., M.C., the Arabian order "El Nahdah," and twice the "Order of the Nile," and was mentioned in despatches several times.

After the War he was with Lord Allenby at the "Residency," Cairo, as Director of the Arab Bureau.

In 1921 he had to leave Egypt on account of ill health, arriving in England on March 28th. He died suddenly six days later, April 2nd.

ANCIENT EGYPTIAN METALLURGY.

BY

MAJOR H. GARLAND,
O.B.E., M.C., F.C.S., M.INST.METALS,
LATE SUPERINTENDENT OF LABORATORIES AT THE "CITADEL," CAIRO,

AND

C. O. BANNISTER, M.ENG., A.R.S.M., F.I.C.,
PROFESSOR OF METALLURGY IN THE UNIVERSITY OF LIVERPOOL.

With Frontispiece and 113 Other Illustrations, Including Many Photo-Micrographs.

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PREFACE.

THE note attached to the Frontispiece of this volume tells the tragic story of the death of the distinguished author six days after his return from the scene of many years' labour. During these years in Egypt Major Garland had exceptional opportunities for the collection and thorough examination of ancient metal specimens not easily obtainable by other metallurgists. Messrs. Griffin once again have served metallurgical students by encouraging the author to put together in book form his extensive notes and critical memoranda which otherwise might never have been made public. Unfortunately, a chapter on Gold and Silver, intended to be included, was only represented in the Manuscript by notes too scrappy to be of any real value.

It was a delicate task entrusted to me by the Publishers to examine and edit the extremely interesting and informing notes, and give them their final arrangement for publishing, but it has proved both fascinating and instructive.

The practical points brought out by this work are (1) The value of microscopical examination in the study of ancient specimens: (2) The probability of a much earlier iron age in Egypt than that generally accepted: (3) The early use of the "cire perdu" process for castings; and (4) the comparatively late use of cold working associated with annealing for the shaping of vessels, etc.

The work of ancient people on the metals known to them has been always of great interest to metallurgists, and the details of Ancient Egyptian Metallurgy given in this book are commended with confidence to students, whilst archæologists will find many enriching suggestions.

C. O. B.

LIVERPOOL,
December, 1926.

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ANCIENT EGYPTIAN METALLURGY

CHAPTER I.

SOURCES OF METALS TO THE ANCIENT EGYPTIANS.

(*a*) Outline of Egyptian History.

To the thoughtful person of the present day it must appear remarkable that man had inhabited the earth for hundreds of thousands of years before he began to use metals. During that tremendous lapse of time he had emerged from a state of utter barbarism, and, if we are to believe some scientists, had developed from an animal propelling himself on four legs into a being of human form capable of making implements and weapons for industrial and warlike purposes.

The primitive natives of Egypt, like those of other prehistoric lands, in their search for improvements upon the stone-throwing methods of hunting and warfare of their simian coinhabitants, quickly learnt to fashion very useful implements of flint, and before the beginning of the historic age, the workmanship of these reached a

standard of excellence superior to that of any other ancient country.

Egyptian history may be traced back some 5,000 years. Before that, we only know that man existed and that a certain stage of civilisation had been attained immediately prior to the invention of the art of writing, at which point all history begins.

The first general application of metals in Egypt does not appear to have been very much anterior to the invention of writing. No doubt the cutting and engraving of stones upon which records and memoirs were to be made, called for tools of a material less friable than flint, with which it was only possible to make rough scratchings upon the surface, and the ancients were thus compelled to try other minerals that were lying in plenty around them, being thus led forward to the discovery of metals, which advanced the art of recording thoughts and deeds to an extent now difficult to appreciate.

It is, however, not improbable that metals had their first application in destructive implements. In spite of the excellence of design and workmanship that the manufacture of flint arrow tips, knives, and other small implements had reached, it is certain that the discovery of metals had a profound and beneficial influence upon the methods used in war and hunting, by rendering possible the production of much more serviceable weapons than those previously in use.

Much discussion has taken place amongst archæologists as to the actual country and time of the first use of copper and other metals, and it is a very fascinating subject. There is, however, little doubt that if the Egyptians cannot be said to have been the first to apply copper to their needs, they were amongst the first, and

they are equally as deserving of credit for it as the other ancient nations who may or may not have anticipated their discovery, because their application was independent and original. Further, it may be said that in their application of the then known metals, each in its most suitable direction, and in their skill in fashioning and working them, the Egyptians were second to no other people of their time.

It has been assumed by some experts that immediately prior to the 1st Dynasty, Egypt was invaded by a foreign nation who brought into the country much refinement in art and statesmanship, as well as a knowledge of metals and other evidences of a matured civilisation. This would mean, however, that in some other ancient country there previously existed a race of people of superior culture, who must, therefore, have been the fathers of civilisation, but up to the present none of the lands of the old world has produced distinct indications that its state of progress was in advance of that of the Egyptians 3,400 years before Christ.

Previous to 1000 B.C., all the chief useful metals were being worked by the Egyptians, and the only ones that are now of extensive industrial importance, and were then unknown, are zinc, nickel, and aluminium. Of zinc and nickel, it may be said that, although they seem indispensable to us now, we could manage without them as did the ancient Egyptians, whilst aluminium is a metal of quite modern discovery, which has only become indispensable since aviation became a practical science. It is not unlikely that, had large deposits of zinc and nickel ores existed in the country, the Egyptian craftsmen would have discovered and used them. They certainly used all the metals that occurred in their own country in sufficient quantities to be of use, and readily

took up the use of tin when it was introduced from other countries, there being no tin-bearing minerals in Egypt itself.

It is almost impossible to realise how much mankind in general owes to-day to the discovery of metals. It will only be necessary to place before the reader a picture of a world minus machinery, which besides owing its origin to the inventive genius of modern man, was primarily made possible by the discovery of the useful metals. Practically all modern improvements depend directly or indirectly upon metals, and our present state of progress would have been impossible without them.

Archaeologists divide the earliest history and pre-history of a country into periods represented by the different and progressive stages of culture that existed, and to these the terms—Stone, Bronze, and Iron Ages are applied. Each of these stages is further divided into early, middle, and late periods, to which suitable names are given. No precise dates can be assigned to the different periods in any country, because they are merely stages which gradually shade off into one another, as, for instance, in the case of the Bronze Age, because stone implements continued to be made for centuries after the first use of copper or bronze.

It is usually considered with regard to Egypt that the Stone Age terminated about 4000 B.C., but there is really no hope of our ever being able to fix a date, even roughly, for the earliest metal objects, because they are prehistoric.

The Stone Age was followed by a period during which copper was used. Afterwards, on the introduction of tin, the Bronze Age proper began. These classical stages of civilisation will be referred to later, as also will the highly contentious subject of the commencement of the

Iron Age in Egypt, a stage of culture which may yet be proved to have even preceded the Bronze Age in this country of paradoxes.

Attempts are sometimes made to trace a definite line of demarcation between these various periods, but surely it is a mistake to expect that an age of, say, bronze would, under any circumstances, suddenly, or even in a century or two, change to one of iron simply because of the introduction of the latter. For instance, in our own time, the invention of electric light did not at once seal the fate of gas illumination, but the two illuminants were afterwards employed side by side, as no doubt they will continue to be for generations. And further, may it not be said that even to-day we are almost as much in an "aluminium" age as a steel one, which latter term is sometimes used in connection with the present era.

It is, therefore, not remarkable that the dates of the commencements and endings of the stages of culture in prehistoric and early historic times cannot be fixed definitely. After the Bronze Age began, flint would be (indeed it is known that it was) used for generations, and similarly, after the introduction of iron, bronze continued to be used. Even after flint disappeared from general industrial use, it continued for ages to be employed for fire-raising purposes, and bronze has never wholly gone into disuetude, even temporarily; in fact, it has remained in use, as we shall discuss later, made up of very similar proportions of the constituent metals as when first introduced thousands of years ago.

It is proposed to give here only a very rough outline of early Egyptian history, in order that the reader may be in a position to follow more readily the allusions to periods and dynasties that follow in subsequent chapters, and for fuller details the authentic works of Professor

Flinders Petrie, Sir Gaston Maspero, and others should be consulted.

The history of ancient Egypt is divided into periods or epochs, which are further subdivided into dynasties in a somewhat arbitrary manner following a system first adopted some 2,300 years ago by an Egyptain historian named Manetho, and which has been accepted by archæologists with varying amounts of credence. There is also a predynastic period, during which the separate states formed by the original incursionists into the Nile Valley were gradually amalgamated into one nation under one Pharaoh. In this remote period small articles of copper, such as pins, and thin articles from hammered gold were made, having been probably hammered from native metal, whilst jars and bowls of exquisite symmetry were produced from the hardest stones by processes of simple grinding alone.

The 1st Dynasty dated from about B.C. 3500, and, as the art of writing was at that time well advanced, we know from records which have been preserved that even the Egyptians then obtained supplies of turquoise from the peninsula of Sinai.

It also seems perfectly clear that in the remote days of the 1st Dynasty the Egyptians had an intimate knowledge of copper ores, and of the processes for extracting the metal, which supports the view that the first use of copper in this part of the world must have preceded the 1st Dynasty by centuries.

As has been mentioned already, in the prehistoric period, gold had been worked, and by the time of the 1st Dynasty the goldsmith's art had reached a high state of perfection, though present-day members of the craft will probably not wholly agree with those archæologists who unfavourably compare modern goldsmiths'

work with the old Egyptian *chefs d'œuvres.* Before the close of this dynasty moulding was known and gold and copper casting were in use.

The IIIrd Dynasty terminated what is sometimes called the archaic period.

During the IVth and subsequent Dynasties mining operations for turquoise were vigorously carried on in Sinai. Gold was obtained from the hills along the Red Sea and a few other places in Egypt. Stone was quarried all over the country to produce the pyramids, statues, and tombs. Huge blocks of granite, 50 to 60 tons in weight, were brought down the river from the district of the first Cataract. It was a period when art and industry flourished as they had never previously flourished anywhere in the world. Gold and copper were used; silver was known, but was rare, and, therefore, much more valuable than gold.

In those early days, metals must have been entirely monopolies of the Court. The expeditions to the mines and quarries were sent in charge of the highest officials, sometimes even the King's sons, and so, no doubt, the first metallurgists in the world were either of royal blood or occupied posts of great importance under the crown.

During the Memphite period, tin was possibly first introduced from abroad. With the exception of a small pin of bronze stated to date back to the IIIrd Dynasty, and which is usually regarded as an accidental production of copper-tin alloy, the earliest article supposed to be of bronze that has been found, is a life-size statue (Fig. 1) of a King named Piupi I., of the VIth Dynasty (see also Chap. II., p. 36. It is now in the Cairo Museum, and, although the Museum catalogue asserts that this statue is of bronze and gives an analysis, doubt exists in some quarters as to whether it is really of that alloy, and a

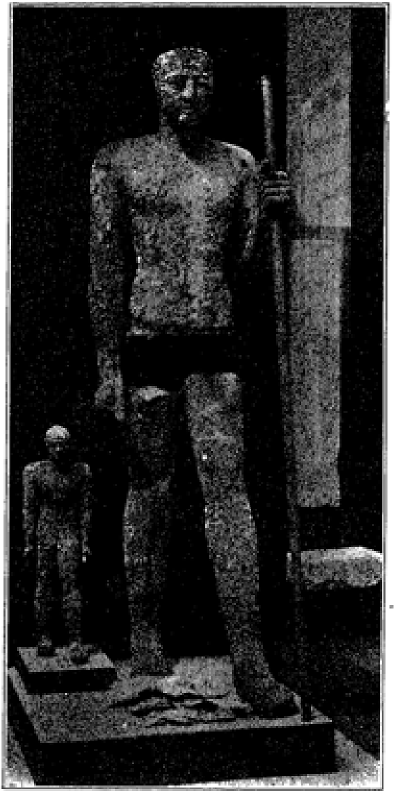

Fig. 1.—Metal Statue of King Piapi I., with a smaller one of his son. Cairo Museum. vith Dynasty.

future analysis may show that it is only copper, in which case the introduction of tin into Egypt will stand in need of being dated forward some centuries, because there is no other authentic bronze specimen in existence of a period anterior to the XVIIIth Dynasty.

At the same time, it should be pointed out that the statue, having been either partly, or, as the author believes, wholly produced by casting, the metal may quite probably be of bronze, as some difficulty would have been experienced in casting an object of this nature in even only comparatively pure copper.

Existing specimens make it fairly certain that during the IVth Dynasty, or even before, iron was employed in Egypt for industrial purposes, but a discussion of this fascinating subject is reserved for a subsequent chapter.

The Memphic Period was followed by the first Theban (from Thebes, the new capital) Period or Empire, which included the XIth to the XVIIth Dynasties, and terminated about B.C. 1600.

The XIIth Dynasty stands out as a very prosperous one, and during its course the Egyptians made an invasion of Syria, another wealthy land of old times, which was subsequently to become an important source of metals of all kinds to the victorious Egyptians.

From the ancient records we learn that in the XIIth Dynasty the mines in Sinai were administered in a methodical manner. Each mine was placed under a foreman and a regular output of ore expected from it. Values were at this time reckoned in terms of weight in copper, and again the archæologists tell us that the jewellery of the period comprised regal ornaments, the workmanship of which has not been surpassed by later-day goldsmiths.

In the British Museum is a memorial tablet or stela

of a mining inspector of the XIIth Dynasty. On it he states that he worked the mining districts and made the chiefs wash out the gold.

The XV. and XVIth Dynasties were foreign ones, the Egyptians' first experience of alien rule. The invaders came from Asia, and are known by the name of Hyksos. They only ruled for about a century, but during that time became thoroughly Egyptianised, assumed Pharaonic titles, and appropriated the statues of kings who had reigned before them. Their rule had little effect on the art of the period, and none on the Egyptian industries and crafts; in fact, in all likelihood, they were ruling a people far in advance of themselves in these matters.

The first Theban period ended in great confusion with the XVIIth Dynasty. The Egyptians overpowered their rulers, chased them out of the country, and an Egyptian Pharaoh was once again set upon the throne.

The XVIIIth Dynasty ushered in a new epoch, the second Theban, or, as it is sometimes called, the Empire Period: a period of majesty and might for the country, during which Asia was subdued, and Nubia, the country of gold, was forced to pay an annual tribute of from 600 to 800 pounds weight of the precious metal from the mines there, which afterwards became a continual source of income to the Egyptians.

That the mines and quarries were kept in the hands of the reigning monarch is shown by the Pharaohs' great interest in their development. Ahmose Ist, the first king of the XVIIIth Dynasty, made visits of inspection to them. This dynasty witnessed the rise of a great queen, named Hatsheput, who reigned as co-regent with King Thutmose IIIrd. This royal lady is noteworthy because she erected two immense obelisks at Karnak, each weighing over 350 tons, and overlaid with gold.

The appearance of the untarnishable covering of these monuments, shining in the splendour of the Egyptian sun, must have been entrancing, and the value prodigious.

Thutmose IIIrd was an able administrator, an empire builder, and a military strategist of no mean order. He increased the treasury of the kingdom by immense quantities of gold and silver, which he captured in Syria, and we read in the ancient records that during his reign a weighing of about four tons of gold took place. He occupied his spare time in designing vessels needed for the temple. His son, Amenhotep IInd succeeded him, and ably administered the Empire, increasing enormously the wealth of the treasury by his conquests. After one of his expeditions he brought back three-quarters of a ton of gold and about 45 tons of copper. During this reign there was considerable intercourse with the eastern Mediterranean countries, and Egyptian influences worked upon the art of other nations. Silver became more plentiful than hitherto, and cheaper than gold.

Another Pharaoh, Amenhotep III., maintained the empire for nearly 40 years, but after that the XVIIIth Dynasty drew to its close in disorder and religious revolution: the Syrian dependency was lost, and priestcraft assumed a controlling influence in the government.

The XIXth Dynasty, B.C. 1350 to B.C. 1205, includes the first two kings known by the name of Rameses, a name which is now renowned almost all over the civilised world. It is the conceit and purloining proclivities of the second Rameses, however, that have brought the name into such prominence. His conceit took the form of erecting collossal statues of himself all over the country, whilst his piracy, in adopting numerous statues of his kingly predecessors, erasing their inscriptions and

substituting his own name and achievements. In spite of these weaknesses, he was a mighty builder, and, as an instance of this, one of his statues may be quoted, which is made of a single block of stone weighing about a thousand tons. The student will find it interesting to picture the ancient Egyptian workmen preparing the stone, moving the statue, and erecting it, without the use of machinery of any kind, and, according to archaeologists, without any other small tools than those of copper and bronze.

Amongst the other achievements of Rameses II., it may be mentioned that he had 51 daughters and about twice that number of sons. His mummy is in the Cairo Museum, and visitors may gaze upon the face of the old king much the same as it must have been as he lay upon his death bier, thousands of years ago.

Unfortunately, the successors of Rameses II. of the same name, who formed the XXth Dynasty, were not so enterprising, and little is known about them, except that under their rule the Empire fell away and the power of the Pharaohs became thoroughly subordinate to that of the priests. A photograph, taken from a beautifully executed bronze statuette of Rameses IV., will be found in Fig. 2.

The later Rameses, in their desire only for ease and luxury, allowed the priesthood to become powerful and wealthy, and so the following dynasty, the XXIst, was one of priests, known as the Priests of Amon, who succeeded in getting the whole of Egypt under their control for a time. Towards the end of the dynasty, however, the country split up into two kingdoms, the priests maintaining authority in Upper Egypt, whilst descendants of the direct royal line rose up in the Delta, and set up a king of their own at Tanis.

From this unsettled period we have relics of interest to the metallurgist. It is not surprising to find that the priests, who seemed to believe that temporal as well as spiritual rule could be worked from one department, did not shrink from commercial undertakings. The

Fig. 2.—Bronze Statuette of Rameses IV.

control of all the metal was placed in the hands of high officials of the priestly house, and thus we find that one, who was the chief of the metallurgists, also bore the grandiose title of "Superior of the Secrets." A picture

of this interesting person is given in Fig. 3. It is a photograph of the cartonage placed over the mummy, and is supposed to be a life-like representation of the deceased. Metallurgists visiting the museum at Cairo may thus

Fig. 3.—An Early Egyptian Metallurgist. Photograph from Cartonage.

look upon the features of one of the earliest of their predecessors in the science, and will no doubt wonder whether the expert was really as youthful as he is represented.

It is owing to the liberal policy of the Egyptian Antiquities Department in allowing photographs to be freely taken in the Museum, that it is possible to include this and other interesting reproductions of antiques kept there.

After Egypt had been more or less divided for about a century and a half, a Lybian succeeded in obtaining the throne, and in bringing the whole of the country under one crown, but the high priests of Amon still maintained their power in certain localities.

During their domination, the Lybians became Egyptianised, as the other alien rulers did before them. However, they were overthrown in turn by Nubian invaders, who founded the xxvth Dynasty (B.C. 712 to B.C. 663). Like their predecessors, the Nubians, or Ethiopians, had no arts or industries, and, therefore, did not influence the crafts of the Egyptians, at least not beneficially.

At the end of the xxvth Dynasty the Egyptians had experience of alien rule from another source, though for a comparatively short time. The Assyrians, who in former years had been subjects of the Egyptian Empire, invaded the country, drove out the Nubians, and took the kingship into their own hands.

The leading historians do not state that the Syrians brought in any improvements upon the metal and kindred industries, and indeed their domination seems to have been of a purely destructive nature, although it was such a short one. They are said, however, to have left behind a set of iron tools, comprising chisels, saws, rasps, etc., of Syrian manufacture, which are still in existence.

The dynasty that followed, the xxvith, extending from B.C. 663 to B.C. 525, forms a bright break in an

otherwise gloomy period of ancient Egyptian history. With the aid of Greek mercenaries, the natives were once again able to overpower their foreign rulers and set a Pharaoh of their own upon the throne. This period of restoration, known from the name of the capital, Sais, as the Saitic Period, is probably the most interesting and important from a purely metallurgical point of view, because it is the only epoch that yields any considerable quantities of metal objects of Egyptian, as well as Greek work and style. Probably 90 per cent. of metal antiquities recovered from excavations belong to this period. In it a great revival of art and learning took place, and Greek influence upon the arts and crafts began to be felt. At least one city of Greeks was founded in Egypt during this dynasty.

But Egypt was far too valuable a land to be unattracted by the heads of rival states, and the Persians, after their victorious march across Asia, entered the country and subdued it, afterwards ruling it with some severity for about 110 years, forming the XXVIIth Dynasty, which lasted from B.C. 525 to B.C. 408.

The Persians were themselves skilled in metal working, and had an art distinctively their own. A few specimens of their bronze work have been found in Egypt from time to time, but, of course, there is nothing to indicate whether these were made in the country by Persian workmen or were merely introduced in their manufactured form.

A system of coinage was initiated in Egypt by the Persians, and in other ways they assisted the prosperity of the country, but the Egyptians, ever ungrateful, threw off the Persian yoke and the Kings of the XXVIIIth, XXIXth, and XXXth Dynasties were natives who held their authority by the help of Greek mercenaries. After some

years, however, the Persians reconquered the country, but only for a short time, and they were finally overthrown about B.C. 332 by Macedonian invaders, who were assisted by the Egyptians themselves.

The history of the ancient Egyptians really terminates at this point, because, after the Macedonian conquest, they were never again free, but so many metal antiquities have been found belonging to the Ptolemaic and Roman Periods which followed, that some note should be made in a book of this nature of the influence on the metal-working craft of these changes of domination.

At the death of the Macedonian ruler, Alexander, in B.C. 305, the Ptolemaic period began, and during its course Egypt became the richest country in the world. Though their rulers were Greeks, the Egyptians were permitted to retain their own nationality, language, and religion. Like previous invaders of the country, the Ptolemies became Egyptianised to a great extent, and adopted the habits of former Pharaohs.

It is to the benefactions of one of the Ptolomies to the temples of Egypt, that we owe the Rosetta Stone, which has proved to be the key of ancient Egyptian hieroglyphic writing, because it was inscribed in three styles of writing, including hieroglyphic and Greek.

No outline of this dynasty would be complete without mention of that remarkable woman, Queen Cleopatra, who was the last of the Ptolomies, and whose character stands embossed in history as a fascinating and powerful one.

The metal antiquities of the Ptolomaic Period, though numerous, are not as plentiful as those of the Saitic Period which preceded it. Although the Egyptians had long been expert in metal working, it is not unlikely

2

that they learnt several new processes from the Greeks, such as the raising of vessels of intricate shape from discs of silver, copper, and gold, which became easy to them as soon as they had learnt to apply systematic annealing.

On the death of Cleopatra, in B.C. 30, Egypt became a Roman province, and it is from that date that foreign influences began to affect Egyptian arts, crafts, and customs in such a pronounced manner that the latter were speedily extinguished, although many of the Roman Emperors could not withstand the fascinations of the Egyptian ritual, for we find that even they adopted the Pharaonic titles and customs, and caused much re-building and repairing to be done to the national temples.

By the time of the Roman Conquest, Egyptian civilisation had once more fallen from its greatness, and consequently the mechanical genius of the Romans found a ready field for its application.

The Græco-Roman Period possesses added interest for the metallurgist, because of the general use of a coinage, and, therefore, furnishes plenty of metal specimens in bronze, silver, gold, and even lead, for the purposes of scientific investigation. The Romans had a mint at Alexandria.

The first use of zinc as an intentional addition to copper dates from Roman times.

During the Roman occupation, the Greek language entirely supplanted Egyptian for official purposes. Christianity was introduced, and, in spite of the persecution of certain of the Roman governors, seems to have flourished as it has never since flourished in Egypt.

The Christians or Copts, as they are still called, broke away from the traditions and conventions of pagan art. As a result of the vigorous persecutions to which

they were subjected by some of the Romans and by all the Arab rulers subsequently, and of their relegation to seclusion in isolated districts and settlements, it is not surprising that, although their forms of architecture, design, and decoration were not without beauty and distinction, following as they did the Byzantine styles, their craftsmanship in stone, wood, and in metal was, on the whole, of an inferior order.

The tenets of their faith may have precluded the employment of skilled pagan artisans in the embellishment of their religious establishments, but it seems more probable that the sculptors, the artists, the metal workers, and other pagan craftsmen were prevented by their own aversion to the new religion, from executing commissions for its followers, because the Copts had no objections to incorporating in their monasteries the hieroglyph-covered stones of former Egyptian temples, or to adopting the foundations of the latter for their own edifices.

The specimens of Coptic metal work that are left to us are generally of poor workmanship, and are not numerous.

Outside the monasteries and settlements, Græco-Roman art supplanted that of the Egyptians. The public buildings and monuments were characterised by beauty of design and finish, but private property appears to have been made much more economically. Much of the metal-work of Græco-Roman types found in Egypt was very probably fashioned abroad, although it must be said that few of the articles will bear comparison with those of the same style found in Europe. The many little bronze figures of the Egyptian gods, which the Greeks conveniently recognised as their own divinities, were no doubt made locally.

In the year A.D. 640, the Romans were turned out of

Egypt by the Arab hordes, who conquered the country and made it a province of their Empire, which it remained until 1517, a period of 877 years. This book is not concerned with early Arab metal work, but it may be stated that specimens of it are not as numerous as might have been expected. The Arab Museum at Cairo, although it contains some very interesting relics in brass and silver, possesses only a meagre collection, which is surprising, seeing that it deals with a comparatively recent historical period. The older mosques of Egypt, however, contain isolated relics of merit.

There are two features of ancient Egyptian history that stand out prominently. The first is the number of changes of capital that took place. From the beginning of the historic period, down to B.C. 332, when the country came under Macedonian rule, no less than nine cities had occupied the position of metropolis, and some of them more than once. The second feature is the persistence of native art, industries, and religion. Not one of the foreign invasions until that of the Greeks, which was really not an invasion, can be traced to have had any serious or lasting influence upon the art of the country, but instead we find, as we have observed previously, that, owing, no doubt, to the advanced civilisation of the Egyptians, the foreign rulers became Egyptianised and adopted the manners and customs of their new subjects. Even the advanced but clumsy art of the Assyrians, with whom the Egyptians had the closest relations for centuries, as subjects and masters, and also as traders, did not have any permanent effect upon Egyptian style, or upon the processes of industry. On the other hand, Egyptian influences considerably affected the civilisations of the different foreign states that came into contact with them. It is certain that the Egyptians

had nothing to learn from any of their neighbours in the manipulation and use of metals, right up to the Græco-Roman period, and that, in spite of constant intercourse with Crete, Syria, and other metal-producing countries, Egypt developed its bronze industry, and its gold, silver, and other ornamental work, on quite independent lines.

The preceding outline of Egyptian history is necessarily a very brief one. The reader will have observed that it covers a period of some five thousand years, but he should take note that early Egyptian chronology is by no means a settled matter. Archæology is a science based almost wholly upon inferences and indications. There is very little documentary or direct evidence of any kind concerning some periods of considerable extent, whilst in many cases the doubtful testimony of classic literature has to be accepted as the only source of information.

In fixing dates for the earliest events, there are several systems of chronology in use, each of which receives its measure of support from Egyptologists equally eminent. There are, however, disparities of thousands of years between the dates assigned by them to the commencement of the dynastic period, and we can only expect very rough approximations in the dating of matters and events so indefinite. For instance, we may compare the system supported by the late Sir Gaston Maspero and others, which places the 1st Dynasty at about B.C. 5000, with that advocated by D. Breasted in his incomparable *History of Ancient Egypt*, a work which, either in its extended or abridged form, the student would do well to consult. In it he used what is termed the short system, which places the 1st Dynasty about B.C. 3400.

Just as there are different systems of dating, so are there various systems of spelling and writing the names

of Kings, and the casual reader will probably find a little difficulty in tracing the same persons and places in the histories and account of different modern writers. Some archæologists show an unfortunate taste for a method of writing the name, which appears to the layman to render them cumbrous and unpronounceable.

The science of archæology is a very comprehensive one: indeed it may almost be said to embrace all the other sciences as well as the arts. And this is probably why we occasionally find in works on the subject, that we are asked by writers in their enthusiasm and admiration for the prowess of the ancient Egyptian artificers, to believe that they achieved the impossible.

This tendency to over-rate and flatter has been extended to metallurgical matters. It fostered the idea that the ancient Egyptians possessed secret hardening processes for copper and bronze, and it has considerably hindered the acceptance of any theories as to the knowledge and use of iron by the early dynastic Egyptians.

With regard to dating, a word of explanation is necessary. The reader who finds two different authorities assigning one and the same event to dates 1,500 years or more apart is apt to become completely sceptical in the matter. Yet the explanation is a simple one. Some years ago an ingenious method of fixing the date of certain events in ancient Egypt was discovered, based on the facts that the Egyptian civil calendar contained only 365 days instead of approximately 365¼, and that in consequence the seasons were always becoming gradually displaced by ¼ day each year, or one day in four years, and so coming round to their correct positions in the calendar every 1460 years (365 × 4). If in a given year of a given king we are told that a certain date of the civil year corresponded with a certain date of the

true or solar year, we can by a simple piece of arithmetic fix that year to its position in a "Sothic Cycle" of 1,460 years, but we can never be sure, from mathematical considerations alone, which Sothic Cycle, for such cycles began in 4241 B.C., 2781 B.C., and 1321 B.C. With regard to the XVIIIth Egyptian Dynasty, from which we have three of these so-called "Sothic Datings," there is complete agreement between Egyptologists that it is to the last of these cycles that the events must be assigned, and working on this basis we get for the beginning of that dynasty the date of 1580 B.C. With respect to the XIIth Dynasty the position is slightly different. Here we have one Sothic Dating, which would place the beginning of the dynasty in 2000 B.C. or 3460 B.C. (1,460 years earlier), according as we place it in the second or first of the cycles enumerated above. It may be said at once that the large majority of Egyptologists agree in accepting the lower date, 2000 B.C. The higher date, 3460 B.C., has now only one advocate of any distinction, though a few scholars are inclined to deny the validity of the Sothic method of dating, and to adopt arbitrary dates in between the higher and the lower. Before the XIIth Dynasty all is guesswork, but here again there is a fairly general agreement that the Ist Dynasty should be dated very roughly about 3400 B.C. Certain Egyptologists would place the date much further back than this, but there are no advocates for a much lower date.

The dates from the XVIIIth Dynasty to the XXXth may be regarded as approximately certain, being based on the known lengths of the kings' reigns and checked, in the later period, by external parallels.

The following table gives a survey of the chronology adopted by the advocates of the Lower Dating :—

Archaic Period, Ist to IIIrd Dynasty, .	3400 to 2900 B.C.
Old Kingdom, IVth to VIth Dynasty, .	2900 to 2475 B.C.
First Intermediate Period, VIIth to XIth Dynasty, ...	2475 to 2000 B.C.
Middle Kingdom, XIIth Dynasty, . .	2000 to 1788 B.C.
Later Intermediate Period, XIIIth to XVIIth Dynasty, ...	1788 to 1580 B.C.
XVIIIth Dynasty, ...	1580 to 1350 B.C.
XIXth Dynasty, ...	1350 to 1205 B.C.
XXth Dynasty, ...	1205 to 1090 B.C.
XXIst Dynasty, ...	1090 to 945 B.C.
XXIInd Dynasty, ...	945 to 745 B.C.
XXIIIrd Dynasty, ...	745 to 718 B.C.
XXIVth Dynasty, ...	718 to 712 B.C.
XXVth Dynasty, ...	712 to 663 B.C.
XXVIth Dynasty, ...	663 to 525 B.C.
XXVIIth Dynasty, ...	525 to 408 B.C.
XXVIIIth Dynasty, ...	408 to 399 B.C.
XXIXth Dynasty, ...	399 to 378 B.C.
XXXth Dynasty, ...	378 to 340 B.C.
Ptolemaic, ...	332 to 30 B.C.
Roman, ...	30 B.C. to A.D. 640
Arabian, ...	A.D. 640 to 1517

(*b*) Sources of Metals to the Ancient Egyptians.

The mines from which the ancient Egyptians obtained supplies of the different metals they used, with the exception of silver and tin, were situated chiefly in parts of Egypt between the Nile and the Red Sea. In these areas were found gold, copper, lead, and iron, as well as various precious stones, for which extensive mining operations were also carried on.

Over 100 ancient gold workings have been traced in Egypt and the Sudan—but none in Sinai. It is not impossible that supplies were obtained at times from the land of Midian, on the eastern shore of the Red Sea,

where old workings are known to exist, but these have not yet been properly examined.

There is in existence a plan of a gold mine dating from the XIXth Dynasty, and this ancient and valuable document, being the earliest map of any kind that we possess, shows, in a somewhat sketchy manner, the mountains from which the gold was obtained, the site where the washing was done, and the store house, together with the roads connecting these places, but the actual position of the mine has not been determined, as the data given on the map are insufficient.

From other contemporary records, it has been found that the metallic gold was obtained by crushing the quartz, grinding and washing on inclined planes, much in the same way as vanning is done to-day. The grains of gold were afterwards melted and run into ingots. The gold contained a fair proportion of silver, as such native gold usually does, but it is improbable that the earliest Egyptian metallurgists knew this, or, if they did, that they were aware of any processes for separating it, in fact analyses made by Berthelot show that the gold from early mummies and other antiquities contains about 13 per cent. silver.

It is likely that some of the first gold articles were made by simply hammering native nuggets, or by welding several nuggets together, but this must have been confined to small articles.

The large quantities of gold objects brought back by the Egyptians after raids and conquests in Asia and elsewhere must also not be forgotten when considering their sources of supply. These spoils of war appear to have been received in various forms, such as ingots, rings, sheets, and even finished vessels of different types, the latter being probably afterwards melted up for other uses.

With regard to the sources of silver, we have not so much evidence. It is well known that in the earliest periods, silver was much more valuable than gold, and that electrum, an alloy of gold and silver of indefinite proportions, was always much prized throughout the days of antiquity. Silver must, therefore, have been at first a rare metal. The late Professor Gowland considered that the first silver in Egypt was obtained by refining the gold from Nubia, but there is no record as to the period in which the Egyptians first learnt to purify their gold, or to separate the silver, though it is fairly certain that later in history they did separate it as chloride by the action of common salt.

It seems more probable that silver was first obtained from Syria, than that it was separated from impure gold, as the latter would imply that the presence of the silver in the gold was known at the time, and that the Egyptian metal workers were possessed of some chemical knowledge, of which there is no evidence. Their medical prescriptions show a lamentable state of ignorance in this direction.

Before rejecting the above theory on the score that silver was not even in use in Syria at the earliest period to which silver objects found in Egypt have been attributed, the systems of chronology of these two parts of the ancient world must be thoroughly verified and co-ordinated.

With respect to copper, we are on surer ground, for there are still in existence traces of old workings, such as heaps of slag, broken crucibles, besides definite written accounts of the mines and their organisation. With some breaks during revolutionary periods, when any metal required by the authorities would probably be taken from the statues and other works of their pre-

decessors, the mines were worked during the whole dynastic period.

The cupriferous ores of Egypt were of a readily reducible nature, being, so far as we can tell to-day, chiefly blue and green carbonates and silicate, whilst ferruginous and siliceous sands for use as fluxes during the smelting of the ores were abundant.

As in the case of gold and silver, spoils of war and tribute from different parts of the empire, were responsible for imports of large quantities of copper. Considerable amounts were also, no doubt, received in the ordinary course of trade with neighbouring people, such as the Phœnicians, at least from the time of the VIth Dynasty.

It is generally agreed amongst experts that the first production of metallic copper, wherever it took place in the ancient world, was an accidental one, and that it occurred round the camp fires where pieces of ore were used as stones to enclose the fire, and were thus reduced by the fuel and the heat. The first knowledge of other metals may also have been brought about similarly. The lump of metal produced fortuitously in this way would quickly attract attention by its properties of toughness, malleability, and lustre. Iron, copper, tin, lead, and silver might have been produced in this manner, but after the first discovery, which appears to have been that of copper, other surface minerals must almost certainly have been methodically experimented upon.

Copper and gold were the first metals to be used in Egypt as in most other ancient countries, but they were obtained by two different methods, so that the discovery of one could hardly have led directly to that of the other, and seeing that at least with respect to Egypt, native gold is far more likely to have existed in the form of

nuggets of useful size, thus needing no smelting for small articles, the employment of gold no doubt preceded that of copper, although copper pins are claimed to have been found in graves of earlier prehistoric dates than specimens of gold.

There is no doubt that in those early times, surface ores of different metals were plentiful, although to-day Egypt cannot be regarded as a country rich in minerals. Its gold deposits are almost exhausted, which is not surprising, seeing that they have been worked for about 6,000 years. Sinai Peninsula remains the only district likely to prove wealthy in minerals: there are considerable deposits of manganese, copper, and iron ores, besides precious stones, such as turquoise, and probably only railway facilities are needed to make them worth the getting.

The next important metal to consider is tin. The source of this metal to the Egyptians is still wrapt in obscurity, and much has been written by archæologists and others on this subject. It is certain that it was imported either in the form of ore or metal, and the various places that have been suggested are Central Europe, Persia, Spain, Britain, Cyprus, and even China. No useful purpose would be served by recapitulating or comparatively discussing these suggestions here, but the reader may take his choice and rest content that it is just as likely to be correct as any of the others.

The probable date of the first use of tin for making bronze is another interesting and much discussed question. As we have mentioned previously, one or two articles of bronze have been discovered belonging to very early dates, such as, for instance, a small rod assigned to the IIIrd Dynasty, but these were either accidental productions, or are perhaps intrusive and belong to later

periods than the accompanying objects with which they were found. At the same time, it is not wise to regard the absence of specimens of any specific class of article during any period of antiquity as conclusive evidence of its non-production by the people of the period in question.

Mention has been made of the metal statue (Fig. 1, p. 8) of the VIth Dynasty King, Piupi Ist, and if this is really made of bronze, it is unlikely to have been an accidental production of that alloy, on account of its size, and, therefore, the first use of tin may date back before that period. On the other hand, it is not until the XVIIIth Dynasty that undoubted bronze objects have been found in sufficient quantities to really justify an assertion that tin was in common use as an addition to copper.

A finger ring of tin, attributed to the XVIIIth Dynasty, is described by Professor Flinders Petrie. It is unique, and, in spite of its extended life-time, the metal still possesses its "cry."

Nothing is recorded to indicate whether its hardening properties, or the colour modifications it introduced, influenced the first use of tin with copper. It should not be overlooked, however, that no doubt the first consignments of tin received in the country were sporadic, and consequently the metal would for some time be procurable only in certain localities or establishments. The ancient Egyptians obtained remarkable results in all kinds of stone working long before they received tin.

The late Professor Gowland went to considerable trouble to show that the first use of bronze in antiquity was probably not an intentional alloying of the two metals, but rather a simultaneous reduction of the two

ores, and he has proved his contention that a sound alloy can be made in this manner. With respect to Egypt, however, it is hardly necessary to prove this, as we know that the copper ore from Sinai was reduced on the spot and brought to Egypt as metal, and that metallic copper was received in tons from other sources.

Antique articles of lead discovered in Egypt are very few, but even prehistoric specimens have been found. The metal appears to have been fairly common in the XVIIIth Dynasty, and it was used occasionally for casting figures of the gods. There is a record that in the XVIIIth Dynasty Cyprus paid tribute in copper and lead, whilst bronze weights were brought up to the standard with lead fillings about that period.

In Saitic times lead appears as an intentional constituent of bronze used for statuettes and similar articles of a purely non-useful nature. The ancient Egyptians appear to have realised that an addition of this metal made the alloy more fusible and more fluid, thus ensuring much sounder castings, especially in pieces of a thin nature. They must also have found that engraving and tooling of all kinds on the leady alloy was much simplified. Whether lead was put in for these reasons, or for economy or fraud, at least up to the Roman times, it is impossible to say, because it is not known whether it was a cheaper metal than copper or tin: it must, however, have been comparatively scarce.

Fig. 4 shows some of the best examples of early Egyptian lead work in existence. The photograph illustrates examples of removable head decorations of various kinds, made for placing on statuettes at will, and date from Ptolemaic times. Some parts of these head decorations were cast direct to the finished form, whilst other parts were beaten to shape. As the photograph had to

be taken of the glass case complete, in which they are kept at the Cairo Museum, the illustration is somewhat marred by reflections and shadows.

Lead coffins also were used in the times of the Ptolemaics.

Fig. 4.—Lead Headdresses.

The sources of lead were probably mainly local. There is a hill near the eastern coast of Egypt, known to-day as Gebel Rusas, which is Arabic for Lead Mountain, where ancient lead workings still exist, and the deposits of galena and cerussite are being exploited at the present

time. Old lead workings also exist at the Jasus Valley near the Red Sea.

The only other metal known to the early Egyptians was antimony, but it is improbable that they regarded it as a metal. A preparation of it was used for colouring the face round the eyes from the earliest times, and it is said that beads of it dating from about B.C. 800 have been unearthed, but it has never been found in any shape or form in which its metallic attributes were required.

Brass was unknown until Roman times. The articles of this alloy found in Egypt belonging to that period may probably have been introduced in the manufactured state. There are apparently no zinc ore deposits of economic value in the country, although calamine occurs at Gebel Rusas in combination with galena and cerussite.

In view of the considerable quantities of manganese ores that exist in Sinai, and also seeing that they were used in the early days in the preparation of glazes, etc., no doubt the Egyptian metallurgists attempted the difficult task of reducing them so as to get the metal. No analyses of Egyptian bronze or copper that have been published show manganese as an ingredient or impurity.

Notwithstanding their different degrees of permanence, we possess to-day specimens of all the metals and alloys known to the ancient Egyptians. The metallurgist, in handling these relics, is seized with a desire to open them up, to pry into their internal constitution and composition, and to get what information he may from a means of investigation which, whilst educative, is unfortunately destructive : the archæologist, on the other hand, touches each fragment almost with reverence ; his thoughts go back to some beautiful queen, with whom he has acquired a thorough post-mortem acquaintance, and visualises

her placing the ornament round her royal neck; or to some pagan temple, every niche of which he knows, and pictures its ponderous wooden doors swinging on the massive hinges of bronze which now lie before him.

However, most of the antiquities, metallic or otherwise, that have been preserved to us by the sandy soil of Egypt, were connected, either directly or indirectly, with the burial of the dead, and it is chiefly because the ancients were so thoughtful of their lives beyond the grave that we are enabled to learn something of the beginnings of the first industries and arts.

CHAPTER II.

BRONZE INDUSTRY OF ANCIENT EGYPT.

At the beginning of the dynastic period, copper founding and manipulation were well understood. The articles made were small and chiefly of a useful, rather than an ornamental, nature. Thus chisels, knives, daggers, and similar implements figure amongst finds belonging to the 1st Dynasty.

Some writers have stated that open moulds must have been employed for making these early tools, as copper cannot be satisfactorily cast in closed moulds. It is very improbable, however, that the copper of these primitive days was sufficiently pure to possess this characteristic, because specimens analysed have invariably contained arsenic, and appreciable amounts of other impurities, such as iron, nickel, cuprous oxide, etc. The following is a typical analysis, being that of a copper dagger of this dynasty :—

Arsenic, ...	0·39 per cent.
Iron, ...	0·08 ,,
Lead, ...	trace
Tin, ...	nil
Bismuth, . . .	nil
Nickel, ...	nil
Cuprous oxide, . .	not determined.

Another authentic specimen of the 1st Dynasty ex-

amined by the author was a copper chisel, the metal of which contained much cuprous oxide, not due to corrosion, but introduced during melting.

From the microscopical examination of these articles and others, their mode of manufacture is quite clear, and the process appears to have continued in vogue for the making of copper and bronze tools and weapons of a plain nature, for many centuries.

The article was first cast approximately to its finished shape, the cutting edges being hammered out afterwards when the metal was cold. This confirms the opinion of Professor Gowland and others that the hardness of the cutting edges of antique copper and bronze implements was due solely to hammering. Some grinding may have been done to the edges, but, as this would remove the hard skins which had been intentionally produced by hammering, it is likely to have been applied to woodworking tools only.

The writer believes that during the IInd Dynasty (B.C. 3000) cored copper castings were being made, but the only specimen that has passed through his hands is a copper spout broken off an *abriq*, or water vessel, authoritatively assigned by the Egyptian Antiquities Department to that Dynasty. This article had undoubtedly been cast on a core, and almost certainly by the wax process which subsequently came to be used so extensively in this country.

A bronze object belonging to the IIIrd Dynasty, which was found at Medum, is alluded to by different authors as a rod and a ring. It is generally regarded as a purely fortuitous production of bronze, chiefly because, if the Piupi statue previously alluded to eventually turns out to be copper, no other bronze object prior to the XVIIIth Dynasty has been discovered. There are, of

course, appreciable numbers of copper articles, such as tools, etc., belonging to intervening periods.

The next dynasty of which important specimens of metal work have survived is the sixth. The life size statue of Piupi in the Cairo Museum belongs to this dynasty; and with it there is also one of his son.

As the authorities decided not to clean the statue, the surface remains crusted with a thick coating of oxychloride and carbonate of copper, but its inlaid eyes of black and white inlay of enamel still give it a very striking appearance. From the photograph which appears in Fig. 1, on p. 8, the reader will be able to form some idea of the attractive appearance it must have possessed when in its original metallic state, probably bearing some delicate and pleasing patina. Unfortunately, the work was not discovered intact, and a kilt supposed to have been made of electrum is missing. Several writers have said that the head and extremities were cast, and that the body and limbs were hammered to shape, the different parts being subsequently joined up by welding. This is quite improbable. The question of alleged welding of copper and its alloys by the ancient Egyptians will be discussed later, but, from his experience of other early metal work and a general study of the whole subject, the author considers it much more likely that all the various parts were cast and rivetted together; in fact, rivet holes can be seen in places. But this opinion is necessarily given with some reserve, as the specimen is kept in a sealed glass case, and the author has had no opportunity of examining it closely. The thickness of the metal of the body and limbs (regardless of the amount of oxidation which now tends to mask it) confirms the author in his opinion, as it would be impossible to raise metal to such perfect external shape by any means

available to the ancient Egyptians, or indeed even at the present time, by hand, unless the metal were very thin when finished.

This statue appears then to have been wholly made by the cire perdu or waste wax process, a method that was not introduced into Greece, the country to which we owe the most perfect antique examples of it, until about 600 B.C.—that is to say, some two thousand years later.

Although the cire perdu process of casting has been many times described, a short outline of it will not be out of place here.

We have seen that the process is of great antiquity, and that, in all probability, the Egyptians originated it: to-day it remains in use in the jewellery and metal work trades with very few alterations or improvements. In its simplest form it may be employed for making solid castings, the model being fashioned in wax, accurate in shape and detail, coated with the moulding substance, and afterwards embedded in sand, loam, or other similar material to support the mould. The whole is then heated and the wax model is either wholly burnt away or poured off through holes left for the purpose or through the "gate" (the hole prepared for admission of the molten metal). The mould is then ready for receiving the molten metal.

According to old records, besides being used as food, honey was available for embalming purposes, and so there was no doubt a plentiful supply of beeswax always to be had for modelling purposes.

The statue of Piupi is our earliest example of a bronze or copper statue made by the cire perdu process. This, like many other smaller statues and statuettes that have been preserved to us, is a cored casting, and the

production of this kind of casting is much more complicated than the simple process described above.

Whether it was for reasons of economy with regard to metal, or lightness in weight of the finished articles, or because of difficulties in procuring large amounts of wax, that hollow casting was introduced, we do not know, but the genius who first invented the process of cored casting deserves to be remembered amongst the pioneers of the founders' craft. We do find, however, that the process was laboriously applied to very small articles, which rather indicates that saving of metal rather than weight was one of the main objects.

The modifications introduced by the ancient Egyptians when doing cored work by the waste wax process were as follows :—

The sand or loam core was formed roughly to the shape of the article to be made, and afterwards it was given a thin coating of wax. This coating received the shaping and moulding at the hands of the sculptor. The mould itself was applied over the wax in the same way as for solid castings, but some means was required for preventing any movement of the core after the wax was run off. Professor Flinders Petrie, in his work on the Arts and Crafts of Ancient Egypt, says that the method by which the Egyptians accomplished this is a doubtful matter, and he goes on to say that out of some hundreds of unfinished bronzes that he has examined, he has never found any connection above the base between the core and the metal. There is, however, no need to confine such examinations to unfinished articles, as in finished ones the core material is often found intact, except, of course, that destructive examination cannot generally be applied to sound specimens, as they are very valuable.

In later times, it is known that iron cross supports passing from the core, through the wax, to the mould were used, and this method continues in use at the present time. Some writers assert that the earlier Egyptians used supports of bronze. This is unlikely, because, being relatively small, the molten metal would melt them when poured in.

The question as to how the cores were secured is, however, not such a difficult one as it appears. The writer fortunately obtained an early Egyptian bronze article, the use of which is not apparent. He submitted it to several archæologists, but none could state the

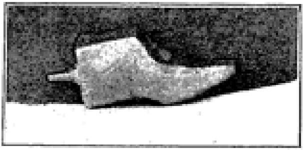

Fig. 5.—Bronze Foot.

probable use of the object; on each side it was engraved with a lotus flower and the Ankle or symbol of life. As will be seen from Fig. 5, it is something like the shape of a human foot, and when received contained a sand core wholly enclosed by the metal. It was, therefore, certain that there must have been some means of holding the former during casting, and a minute investigation showed that an iron wire strut had been employed. The strut was still in place, but, being completely oxidised in the black core material and to some extent diffused amongst it, it was only detected with difficulty.

The struts in small articles being so thin (in the case

of the casting above described the section only measured $\frac{1}{8}$ inch by $\frac{1}{32}$ inch), they are completely oxidised, and only with difficulty can the swollen and disintegrated mass of oxide be recognised amongst the sandy core. The difficulties due to the oxidation of iron wires as described above probably explain why Professor Flinders Petrie has never found a retaining strut in an antique casting of Egyptian origin.

A photograph of a section of the casting referred to will be found in Fig. 6. The position of the iron wire is shown, whilst the portion of the core material per-

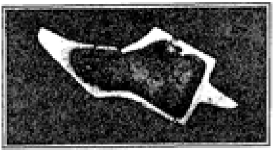

Fig. 6.—Section of Bronze Foot.

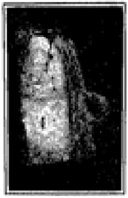

Fig. 7.—Bronze Charm Box.

meated with ferric oxide has been left in place, and is just discernible in the illustration.

Another specimen of a casting with a wholly enclosed core, and which contained the remains of an iron strut, is that shown in Fig. 7. It was intended as a charm, and probably originally contained some part, perhaps a tooth, of a crocodile or lizard. There is a model of the animal on the top. When the author got it, one side had already been broken open and the contents removed, so it is not known what substance the enclosed relic was embedded in. The photograph shows one of the sides

after filing, and the position of the iron strut (wholly oxidised) which was thereby exposed is marked.

The sun and snake emblem, originally fixed to the head of a statuette, and the statuette head shown in Figs. 8 and 9, were both hollow castings, and each had an iron strut. In the former the strut went through the centre, and in the latter it passed straight through the head just above the ears. In both, the diameter of the wire was not more than one-sixteenth inch, and was completely rusted.

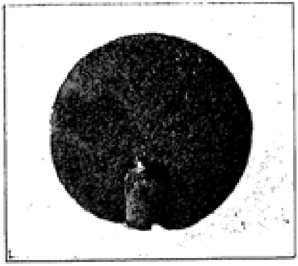

Fig. 8.—Sun and Snake Emblem.

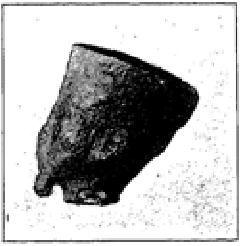

Fig. 9.—Head of Statuette.

It should not be overlooked that most of the cored articles found to-day are small in size and nearly all have at least one hole somewhere, as part of their design, through which a very substantial support of some kind could have passed from the core to the mould, and these small articles would not generally need more than one support. Even the various parts of the Piupi statue could have been cast with no other supports than those which could have been passed through the open end of each piece.

As the cire perdu process of casting gave a perfect reproduction of the finest details of the model, little work was left for the engraver to do afterwards. It was a difficult system to work, because the wax coating had to be very uniform in thickness, in order to prevent flaws in the solid metal owing to unequal contraction at places of varying thickness; and also considerable difficulties in ensuring flow of the metal to all parts had to be met.

One of these difficulties is exemplified in the portion of

Fig. 10.—Statuette of Goddess Isis.

a statuette of the Goddess Isis, bearing Horus on her knee (Fig. 10). The body was cored, whilst the arms and the child had necessarily to be solid. At the part where the right forearm and hand of the goddess join her body, the metal was thick as compared with that of the body itself, and so the unequal contractions of the solidifying metal caused a flaw. This flaw permitted the corrosive elements to penetrate, and so in time produced

the hole seen in Fig. 11, the photograph of the body of the goddess having been taken after the arm had been removed. This difficulty must have been a considerable one in the early working of the cire perdu process by the ancient Egyptians ; and it has not been without influence upon the decay of the products.

Another example of early bronze founding troubles occurs in the peculiar bronze casting, Fig. 5, alluded to previously. When it came into the author's hands one side was bulged outwards and cracked, as shown in

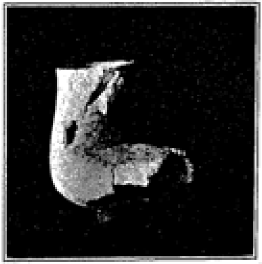

Fig. 11.—Body of Isis : Arm removed.

the photograph. A microscopic examination of a section of this side proved that the bulge occurred during solidification of the metal, and must, therefore, have been due to the gases escaping from the core. The founder evidently had not taken the precaution of thoroughly drying and venting the cores before casting.

The excellent reproduction of detail and decoration in the castings of the ancient Egyptians was partly due to the moulding material used, which was of a smooth,

non-lumpy nature, being no doubt plaster of Paris with a suitable admixture of fine sand or ground brick.

It has been stated that plaster could not have been used, as it crumbles to powder at 260° C., and bronze moulds must be heated to a much higher temperature. As a matter of fact, plaster of Paris, with an admixture of some other more refractory material, such as brick dust, is in common use to-day for bronze casting.

Many of the artistic productions of the early Egyptian copper and bronze founders could not have been produced by any other process. Some are so small that for the undercut parts no methods of coring or sectional

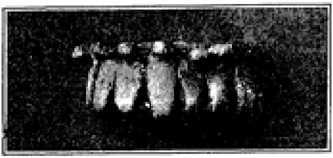

Fig. 12.—Bronze Snake Crown.

moulding would do. The solid castings were generally submitted to much engraving for the fine details, but in most of the hollow work the thinness of the metal prevented this, and so the artist finished the wax model perfectly, leaving very little ornamentation to be applied by the engraver. This system, of course, presented no great difficulties, because the cire perdu process of casting is the one above all others suitable for the perfect reproduction of intricate detail and thin sections.

The bronze multiple snake crown, of which a photograph appears in Fig. 12, shows details of the modelling. The manner of fixing the wax snakes round the frame

is apparent from their overlapping in places at the sides.

Fig. 13 is also of interest, because it shows some details of the foundry practices of the early days. The specimen is an unfinished casting of the legs of a bird. Whether a body was formerly attached to them cannot now be ascertained. The side view shows one runner from the "pour" to the bottom plate or stand, and another joining the two legs. From the shape and form of the

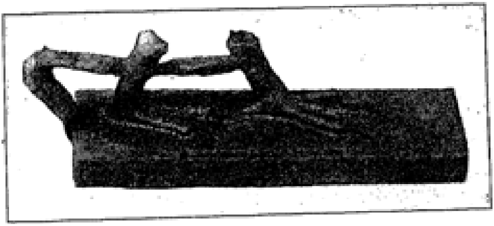

Fig. 13.—Unfinished Casting, showing "Gates."

runners, it is possible to picture the little rolls of wax as the modeller fixed them after completing the model. The Egyptian workers had already found the necessity of having several runners, even in small work.

This specimen was a solid casting, so most of the detail and finishing was left for the engraver to do. In the front view, Fig. 14, the chisel marks left by the engraver after he had commenced to smooth the surface are clearly visible. It is, however, rather curious that he did not remove the runners before he began this work.

The cores found in hollow bronze castings of ancient Egypt have been variously described as blackened sand

with a little organic matter, and as a mixture of sand and charcoal.

They are generally black or of a dark slate colour, being no doubt sand from deposits on the Nile bank similar to that used for founding in Egypt to-day. The author has only come across one example with a core reddened by heat and approximating more to the loam used in English foundries.

The organic matter is chiefly carbon, and when originally added would no doubt have been either bone dust or sawdust, put in with the object of producing the necessary

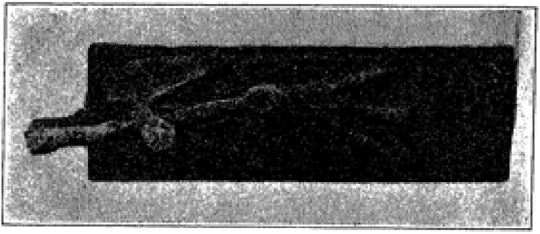

Fig. 14.—Chisel Marks on Unfinished Casting.

porosity when burnt out during the filling of the mould.

One of the best and largest specimens of cored work that has been discovered is the bronze lion that is depicted in Fig. 15, which belongs to the Saitic period, and is supposed to have formed part of a door fastening of some kind. The artistic merit of the production does not call for comment here; it was the effort of the sculptor who modelled the wax, and there was, therefore, no pattern maker to be commended. The actual casting

of the article would present no difficulties, but it may be observed that the links were cast, and their production as a chain would undoubtedly be a pretty little problem for the founder. The measurements of the specimen are 10½ inches high by 25 inches long, and it is hollowed from the end, at the tail of the animal.

Another good example is that of the portrait statuette

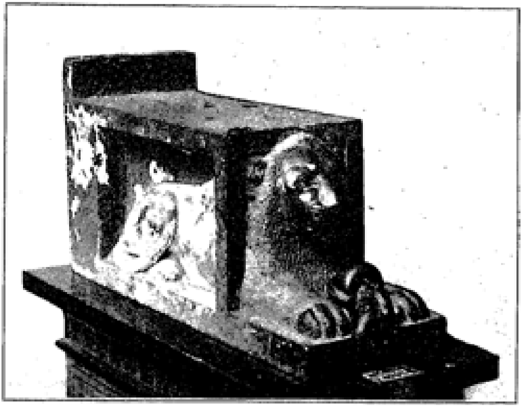

Fig. 15.—Bronze Door Fastening.

of Rameses IV. (xxth Dynasty), the front view of which is shown in Fig. 2 (Chapter I.), and the back view in Fig. 16, of which the limbs are missing. In this case a good deal of tooling was left to be done after the casting was made, and so the metal was made fairly thick. The engraving was very neatly done, both on the back and the chest, and even to-day the statuette preserves a very

striking likeness. The limbs were cast separately and joined to the body in a manner which will be described later. Portrait statues of Pharoahs in bronze are rare and valuable.

Probably the best example of early hollow casting is

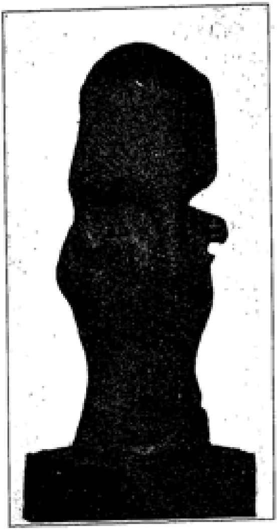

Fig. 16.—Statuette of Ramoses IV. Back View.

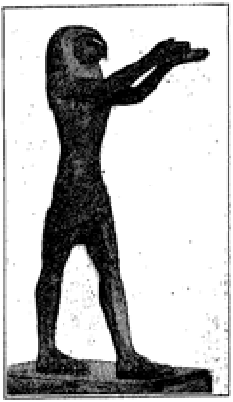

Fig. 17.—Statue of Horus.

a statue of Horus, now in the Louvre, of which a photograph appears in Fig. 17. This specimen is one of the largest in existence, being about half life size, and is stated to belong to the xviiith Dynasty.

Of cored work of Roman times in Egypt, the bronze vase (Fig. 18) may be given as an example. It is, of course, not a specimen of the best work of the Roman period, but it is of interest as showing the remarkable

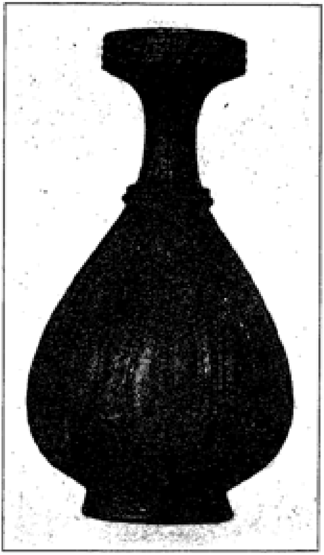

Fig. 18.—Bronze Vase.

regularity of thickness of the metal. The photograph of the half-section (Fig. 19) shows this clearly: the wax modelling must have been perfect.

A good example of a solid casting is given in Fig. 20. This is a statuette of the God Thoth. It was cast in sections and cleverly joined. Had the attempt been made to cast the figure in one piece, it is probable that

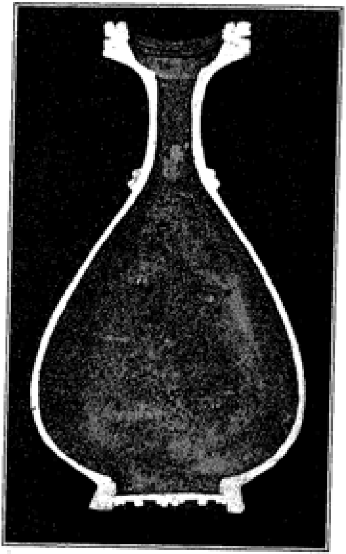

Fig. 19.—Section of Bronze Vase.

the extended arms of the wax model would have tended to droop, and thus have spoilt the work. The modelling was well done, the figure being perfectly proportioned. The attainment of anatomical correctness (in so far as

it follows the human form) in a model made up of separate parts joined together must have been a matter of some difficulty. There are, however, many Egyptian statuettes of even greater merit than this example.

Many of the statuettes, especially those of which the

Fig. 20.—Statuette of God Thoth.

bodies were cored, were cast in sections and the limbs cleverly fitted to the bodies by mechanical joints—that is to say, without any binding medium such as solder or spelter.

These joints were no doubt hidden to some extent by hammering the visible dividing lines, or in some instances by engraving a decorative arm band. Many statuettes are now found minus the limbs, the latter having fallen out of their sockets as corrosion advanced.

The types of joints used by the ancient Egyptians were chiefly variations of the ordinary mortise joint. In the simplest type the two surfaces were ground quite flat, and were held together by a central bronze pin.

This type of joint generally occurs midway between

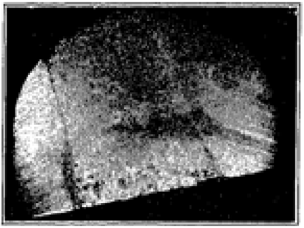

Fig. 21.—Section through Arm-joint.

the shoulder and the elbow; it was also sometimes used for affixing the feet.

The most intricate type of joint that the author has seen is that on the statuette of Rameses IV. shown in Fig. 16.

Fig. 21 is a photograph of an arm-joint cut through the mortise and tenon. The jointing was very well done, and may be taken as an example, on a small scale, of fitters' work of early Egyptian times. The tongue which projected from the shoulder of the specimen is readily distinguished from the two sides of the socket,

because it was made of poorer metal, which corroded more readily than that of the arm itself.

Another pattern of joint which must have required skill on the part of the early workers in order to secure a rigid fit, is that found on the statuette of Horus, in the Louvre, shown in Fig. 17. In this the tenon is not part of the metal of the body, but is separate, and is fitted to the latter in a wedge-shaped seating as depicted in the drawing in Fig. 22. The tenon is simply a trapezoidal projection which was fitted into a suitable hole

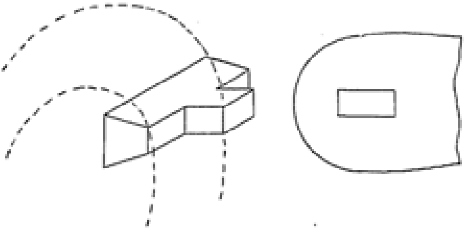

Fig. 22.—Joint of Horus.

through the arm, and the tenon would no doubt be rivetted over afterwards.

Portions of head-dresses, beards, and decorative pieces were also sometimes cleverly mortised into the bodies of statues and statuettes.

The bulk of early artistic casting having been done by the wax process, the craft of the old moulders was less important and less scientific than it is to-day, but still much skill was required in the selection of materials for cores, and in arranging the moulds so that the molten metal would run to the thinnest parts. They certainly specialised in thin castings. So far as we know, there

was no moulding in loam or sand by means of flasks or similar contrivances, and, therefore, no wooden patterns or core boxes were required.

It may be remarked that the ancient Egyptians were very successful in casting metals and alloys which we should regard as being very impure and of unsatisfactory

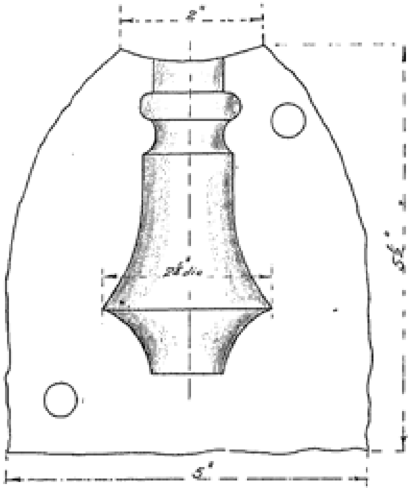

Fig. 23.—Mould for Ornamental Head of Pedestal.

composition. It is almost certain that they always heated their moulds prior to pouring; in fact, most of the finest work could not have been produced otherwise.

Plain articles, such as chisels, etc., were no doubt sometimes cast in open moulds; indeed, some of the

latter are said to have been found, but closed stone moulds in two halves were certainly in use, and even bronze moulds may have been used, but probably not extensively.

There is in the Cairo Museum half of a stone mould of an ornamental head for a pole or pedestal. A drawing of it is given in Fig. 23. It has two replacing holes, and it was clearly used for making shell castings in the manner in which cheap statuettes are produced to-day, by filling the mould and, when a skin has solidified, pouring off the remaining liquid metal. Hollow bronze castings identical in type with this mould have been found, and may be seen in Cairo Museum.

So far as the author is aware, there are no other antique Egyptian moulds for bronze in existence, but two of Assyrian origin may be quoted, as with the considerable intercourse that took place between the two countries during dynastic times, it is almost certain that they were general types introduced into Syria from Egypt, or, conversely, that they must have been introduced into Egypt during that time, although as yet no specimens have been unearthed in the latter country.

The first is a mould made of bronze for making arrow tips found near Mossul; drawings of it are given in Fig. 24, taken from a communication by E. A. Budge to the Society of Biblical Archæology, *Proc.*, 1884, vi., 109. The following is the description given :—

This bronze mould for arrow heads is a perfect specimen; it is 2$\frac{3}{4}$ inches in height and 1$\frac{1}{2}$ inches in width. The movable dies, when fitted in their places, are 2$\frac{1}{8}$ inches across, and the base 3$\frac{3}{4}$ inches. The mould consists of six pieces: an elliptical base, hollowed to a depth of $\frac{7}{8}$ of an inch, containing three tapering bronze points (which formed the cores of the arrows), situated at regular

intervals of half-an-inch from each other, the middle one being 1 inch high, and the other two $\frac{7}{8}$ inch. At each end of this portion (outside) there is a projection,

2

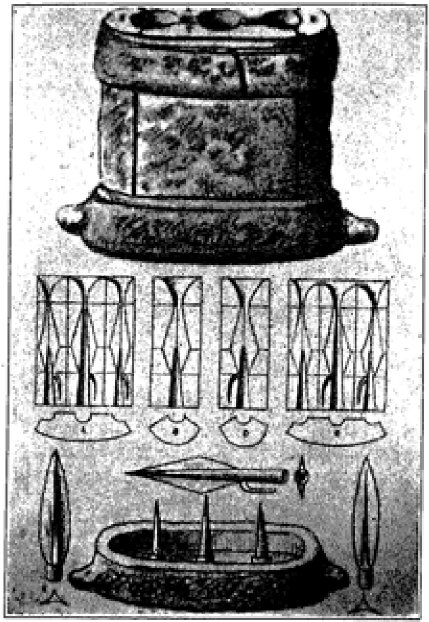

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Fig. 24.—Mould for Arrow Tips.

which would almost lead one to suppose that it was fixed in wood or stone. Four pieces of bronze, A, B,

C, D, being the movable dies mentioned above, fit into the base accurately, and together with it form the actual mould of the arrow heads. The whole is held together by a movable ring of bronze fitting closely over the top of the mould. Three arrow heads could be cast in this mould at one time: two three-bladed, and one one-bladed. The single-bladed arrow head, showing a barb cast on the shaft, is also shown in Fig. 24; the other two castings from the same mould are of the same form, with the exception that they are three-edged, somewhat resembling a bayonet. Drawings (2) and (3) are somewhat similar ones found at Babylon. The inner surfaces of the dies are carefully smoothed, and the dividing lines, slightly engraved in order to ensure precision in cutting the mould, still remain.

It is now in the Babylonian and Assyrian room of the British Museum. The style of arrow tip made by this mould is identical with many that are found on old sites in Egypt, and this fact indicates that this type of mould may have been in use in both countries. The life of a bronze mould used for making castings of the same alloy cannot have been a long one, but it would probably be much longer than the layman might expect, because rapid cooling was ensured by the mass of metal comprising the mould being many times greater than that of the molten metal it was to hold.

In the Louvre there are several unfinished solid Hittite statuettes in bronze with the fins still remaining at the sides, thus showing that they were cast in double moulds. There is also, from prehistoric Crete, a double jewellery mould of granite with replacing holes.

It would seem that in Egypt the best work was always done by the wax process, but that for statuettes of the gods for the poor, who could not afford to pay a sculptor,

repetition castings from stone moulds were probably made.

It is somewhat remarkable that, after taking great pains with the modelling and finishing of bronze statues and statuettes, the Egyptians covered many of them with plaster, just as they did some of their finest sculptures in stone of all kinds. The explanation given for the latter probably also applies in the case of the former. The plaster was put on so that the work could be coloured; they showed great fondness and much aptitude for painting. Figs. 25 and 26 show front and back views of a bronze statuette of the God Osiris, which has pittings chiselled over the body to make the plaster adhere. Many bronze statuettes were gilded in the later periods.

A feature of the bronze work of the Saitic period was the bringing out of detail of dress and ornamentation by inlay.

In many statuettes the eyes were inlaid with gold, but occasionally the whole of the dress and jewellery is found to have been splendidly executed in gold or silver inlay, similar to some Oriental work of to-day and carried out in the same way, grooves having been cut and the inlay metal hammered into them in the form of wire.

One of the choicest examples of this work is the statuette of Queen Koramama, XXIInd Dynasty (just pre-Saitic), in the Louvre. It has an exquisitely traced necklace in gold and silver inlay. Another fine specimen is in the Athens Museum, whilst the British Museum contains several examples, though of less elaborate design. Readers able to do so are strongly advised to visit the Third Egyptian Room of the British Museum.

Another branch of Egyptian bronze founding was that of making weapons, particularly lance and arrow

points. Very few swords of Egyptian make have been found, and it would seem that this weapon was not much used until at least the Græco-Roman times.

Battle axes and daggers were, however, made of copper and bronze from an early date. Specimens of these

Fig. 25.—Pittings on Statuette of Osiris. Front View.

Fig. 26.—Pittings on Statuette of Osiris. Back View.

weapons, bearing chasing and inlay decoration, have even been found amongst the personal equipment in the tombs of queens and princesses, although we must

suppose these ladies carried them for ceremonial purposes only.

At first the arrow and lance tips were simply hammered from cast rods of copper to a flat-pointed section with two cutting edges, but later they were cast in a variety of shapes. Copper and bronze arrow tips were in general use in Egypt until Arab times—that is to say, during the whole of the Græco-Roman times—when iron was commonly employed for other purposes both in this country and elsewhere.

The earliest forms, being simply reproductions in bronze of the types previously used in flint, had a tang,

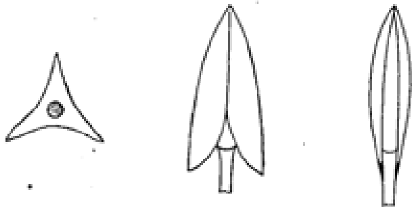

Fig. 27.—Arrow Tip.

as shown in Fig. 27, which was inserted in the end of the arrow and secured by tying. Other forms were cast with a socket, into which the arrow was fitted; no doubt this pattern came in as an improvement upon the tanged type.

Some other kinds of articles for which bronze was employed will be found in the illustrations. The copper nail (Fig. 28) is authoritatively attributed to the XVIIIth Dynasty (B.C. 1500). It was hammered to shape from copper rod, and is very similar to copper nails made to-day for certain purposes. Indeed, but for the fact

that the specimen had a cuprous oxide coating one thirty-second of an inch thick, it might have passed for a modern production.

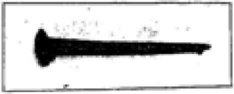

Fig. 28.—Copper Nail. xviiith Dynasty.

The Græco-Roman razor (Fig. 29) was made of impure copper, cast roughly to shape, and afterwards finished by hammering. Readers may ponder over the efforts of a man attempting to shave with a copper blade, but it may be remarked that a highly ground steel razor is not essential, for natives of several parts of the world

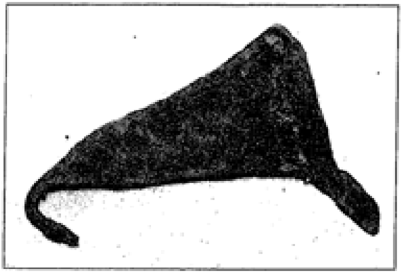

Fig. 29.—Copper Razor.

still effectively carry out this operation with pieces of broken glass or tin-plate.

Besides tools and weapons, the Egyptians made many

domestic utensils of copper and bronze, marked very often by considerable beauty of form.

We have seen that the forming of metal objects by casting is of great age, and probably an equal antiquity may be claimed for another process, "raising"; that of making vessels by hammering sheets of metal to the required shape. The author's experience leads him to think, however, that raising was much less in vogue in Egypt, even up to the Roman occupation, than has been supposed hitherto. The process of beating the metal to shape was, with the exception of gold work, up to the commencement of the Græco-Roman times at least, confined to articles of simple form, and even of these most were first roughly cast to shape. Soldering and brazing being unknown, vessels required with handles, spouts, and similar projections, either had to be cast in one piece, or they had to be made up of raised or semi-raised bodies and cast projections, the latter being fixed by rivets. The former method was more generally used, simply because of the difficulty of making water-tight joints by the other process.

There are several allusions in catalogues of different museums and other relevant works to bronze and copper vessels which are stated to have raised bodies, and cast handles, spouts, etc., welded on, and a similar method of construction has been attributed to the Piupi statue mentioned on p. 36, but the author feels certain that these statements are wrong. Welding of copper or bronze has never yet been satisfactorily accomplished, and even in modern times the joints made by the oxyhydrogen or oxyacetylene process of autogenous welding as applied to these two metals cannot be said to be wholly perfect. Some joints may have been made in early days by pouring molten metal over and around the two pieces to be joined,

the process known as running-on, but this cannot be regarded as welding in the proper sense of the term.

An example of a late Egyptian metal vessel (Roman or Byzantine period) with a spout and a handle is given in Fig. 30. The entire vessel was cast in one piece, and the decoration, after the style of a lion's head, seen on the spout, was done by chisel work subsequently. The evidence for this is given in Chapter V. If this pot formed part of a museum collection, it would very probably be described as having a body shaped by hammering and

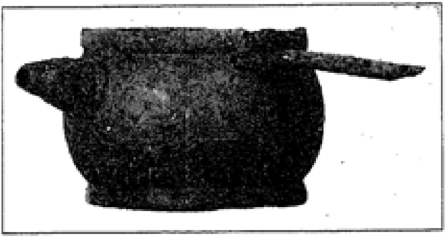

Fig. 30.—Egyptian Vessel (Roman or Byzantine).

cast projections joined together by welding, but it is not so, although it is a very late example.

As a further indication that raising was not in general use even so late as Roman times, the Roman ladle, of which a photograph appears in Fig. 31, may be taken. This article, which could have been made with facility by hammering from a suitably shaped disc of copper or bronze, was cast in one piece.

The catalogues of some museums give accounts of vases, bowls, and other vessels supposed to have been made by raising, but a microscopical examination of the

objects would probably show that many of them were cast.

It is essential to note the difference between raising—that is, the gradual shaping of a vessel by hammering, stage by stage, from a disc of metal—and the forming of such a vessel by casting it roughly to shape and putting on the finishing touches with the hammer. The latter process appears to have been very much used by the

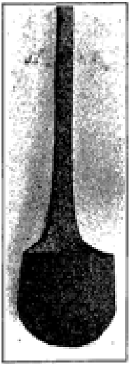

Fig. 31.—Roman Ladle.

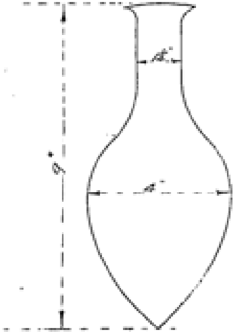

Fig. 32.—Bronze Vase. XVIIIth Dynasty.

ancient Egyptians, but it is quite different from our present method of raising.

The extended use of raising would imply a knowledge of annealing, and of the latter we have little or no evidence. Some of the vessels said to have been wrought from bronze and copper by raising could not have been made without several annealings during the course of their manufacture, as, for instance, a bronze vase of the

XVIIIth Dynasty of the shape shown in Fig. 32, which was used for washing the sandals of the priests. The neck is said to have an internal diameter of $1\frac{1}{4}$ inches, the thickness of the metal $\frac{1}{16}$ inch, and the vessel would not be easy to make by raising from bronze even to-day. The author fully believes that a microscopical examination of the metal would show that it was cast.

It may also be remarked that the tin content of some of the bronzes, and the deleterious impurities of much copper work, absolutely preclude the possibility of their having been wrought to shape either hot or cold.

There is some difficulty in getting for examination specimens of antique objects of the early dynasties which could possibly have been made by raising, as vessels produced by this means must necessarily have been thin, and thin sections of copper and bronze are often found to be entirely corroded, being, therefore, useless for purposes of metallographic investigation.

The question of the time and place of the first methodical use of an annealing process is an interesting, though a somewhat difficult one. Many of the earliest metal objects now found would need no annealing in the course of their manufacture. The cutting edges of tools were hammered cold, in order to produce a hardened surface, and, therefore, annealing would have been harmful and unnecessary.

One article that has come into the author's hands gives us some information on this question. It is a piece of copper strip of the XIIth Dynasty, $\frac{1}{4}$ inch wide by $\frac{1}{16}$ inch thick. Lengths of this copper strip were used by the Egyptians for tying together pieces of woodwork before the days of nails. It would be essential that strips for purposes of this nature should be as soft as possible, and, therefore, it is not unreasonable to suppose

that, had their metallurgists been aware that a thorough annealing conferred the maximum softness, and had they learnt to apply it as a definite process, they would certainly have subjected these strips to the treatment.

The sample was very rich in arsenic, containing about 4 per cent., and viewed under the microscope, it was clear that it had *never* been annealed. There were, however, indications that the strip had been hammered to shape in the hot state from a thin copper rod, and by this means the maker probably obtained the degree of softness that suited his requirements, but never thought of annealing as a distinct operation.

It is almost certain that the hot working of metals preceded the use of annealing processes, and the latter would not become essential until raising was employed for making other than plain articles in copper and bronze. It is extremely improbable also that the ancient Egyptians were able to fashion elaborate articles in bronze and copper in the hot state, especially if we are to accept the statement that handled hammers were unknown. For although we know that their iron was, and in some parts of the world iron is still, forged to shape with handleless stone hammers simply held in the palm of the hand, such a method would not admit of the careful and almost delicate precision, both as to the weight of the blow and the point to be struck, that is essential in forming a vessel of intricate shape from a sheet of copper or bronze.

The copper strip previously alluded to was obtained from the wooden sarcophagus shown in Fig. 33, now in the Cairo Museum. All the wooden joints of this coffin are further secured by strips of this kind passing in bunches through holes made for the purpose and the ends

twisted together. They can be seen in places in the photograph.

When the specimen was received, the copper was in an unusually good state of preservation, with practically no corrosion, having been well protected by the woodwork in which it was embedded, and was probably only slightly less tough than a similar piece of copper of the

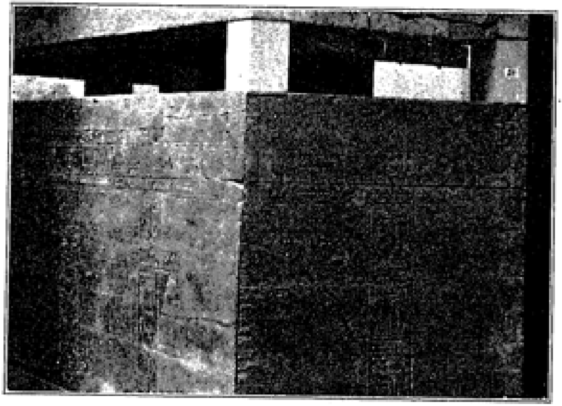

Fig. 33.—Wooden Sarcophagus.

same composition that might be made at the present time. It withstood ten bendings backwards and forwards through 45° before fracture, thus displaying a state of excellence seldom found in old metal productions.

The following is the analysis :—

Insoluble matter,	·12
Lead,	·29
Bismuth,	·03
Tin,	trace
Iron,	·29
Cobalt,	·06
Nickel,	nil
Arsenic,	4·17
Copper by diff.,	95·04

The author has come across no antique Egyptian metal article of periods prior to Græco-Roman times (to which annealing during manufacture would have been beneficial or necessary) which shows indisputable evidence of annealing. There is little doubt that annealing was a fairly late invention.

When dealing with these antique specimens from the annealing point of view, it is necessary to bear in mind the two different ways in which annealing effects in the microstructure may have been produced. Firstly, there is intentional annealing carried out with definite objects in view, and secondly, accidental or fortuitous heating. The latter may be subdivided into annealing due to ageing on the one hand, and that due to unintentional heating, such as fires in buildings, cities, etc., as well as heating during use, such as cooking vessels would be subjected to, on the other hand.

Ageing effects will be discussed in a later chapter; they are trifling in extent. The same cannot, however, be said with respect to accidental heating during the lifetime of the finished article. In such cases we have often external appearances to guide us, although in a specimen some thousands of years old, which may have undergone several changes of situation both before and

after the time at which it was lost or deposited, these indications may have been obliterated. The writer has, therefore, always rejected specimens showing indications of over-heating, such as a coarse granular micro-structure, and so on. These specimens were few in number, and in several of them the external appearance left no doubt that they had been in a fire after manufacture.

In spite of what has been written on the subject, there is no positive evidence of welding or brazing of copper and bronze, or of soft soldering, before late Roman times. Welding of copper or bronze is, as stated previously, out of the question, though some repairs were undoubtedly effected by a process of pouring liquid metal into the hole or around the fracture, as the case required, but this cannot be called either welding or brazing.

As evidence of the general ignorance of brazing or any similar process of joining metals, the Roman vase (Fig. 18) may again be quoted. This vessel, together with another very similar in design obtained by the author, was produced by casting, but the bottom was cast separately, when it might easily have been cast in one with the body. It was not brazed in, but was simply hammered into a conical seating. This is readily seen from the photograph of the section (Fig. 19), and it will be noticed that it was not properly hammered home all round. A photograph of the section of the lower portion of the second vase is also given (Fig. 34), from which the method of fixing the bottom is very clear; the latter remains bent as the hammering left it when put in.

No soldering, brazing, or welding can be detected in the joints of statuettes that were built up of sections and cleverly joined together, and surely if any of these methods had been in common use at the time, it would

have been used for effecting any necessary repairs and for fixing the bottoms of these Roman vases.

A silver bowl attributed to the xxth Dynasty has been stated by one writer to have been probably produced by spinning. In spite of the fact that the forming of circular-shaped vessels by spinning the metal is merely a development of the process of pottery-making on a potter's wheel, it may safely be said that metal spinning was quite unknown in primitive times, and, of course, was not indispensable for the making of the bowl in

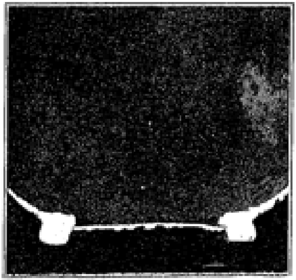

Fig. 34.—Bottom of Bronze Vase.

question, as it could readily have been produced either by casting and afterwards grinding and polishing, or by raising by hand. There is absolutely no evidence that the ancient Egyptians possessed a knowledge of metal spinning, or that they ever had tools that could have been used for such a purpose.

Wire drawing also was unknown. The fine gold wire used in ornamental work was made by cutting strips of the metal from sheets and welding them together.

With regard to the methods used for finishing metal objects we know very little. At first no doubt they applied to metals the processes they had used with such conspicuous success upon stone, as, for instance, cutting, carving, grinding, and polishing.

From the beginning of Egyptian history, grinding and polishing were done on hard stones with exquisite results, in some cases a flawless, glass-like surface being obtained,

Fig. 35.—Bronze Mirror.

and it is known that they had emery, whilst, of course, fine sand existed in abundance. But something more than these materials was necessary for the production of such perfect results, and it would be interesting to know how, and of what substance, they made the powders they used for obtaining the finished surface in both stone and metal.

The mirror shown in Fig. 35 was polished on both

sides, and, strange to say, it is dished on both sides to a depth of about $\frac{1}{16}$ inch at the centre. This may suggest that some kind of mechanical polishing with a revolving bob was used.

Repoussé decoration seems to have been applied only to gold articles at first, and indeed the author does not know of any purely Egyptian work of this kind

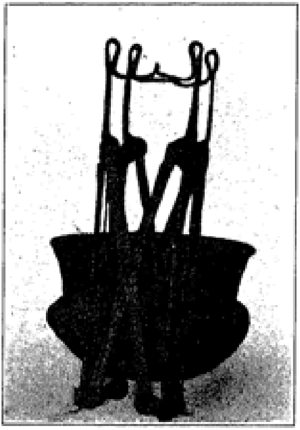

Fig. 36.—Collapsible Stand (Closed).

on bronze or copper. Chasing and engraving were extensively and cleverly used on both these metals; almost every statuette bears some engraving.

In our own time, the methods of working metals by hand—that is to say, those processes requiring no machinery—fall under the headings of founding, raising,

engraving, chasing, engraving inlaying, and repoussé work. All these processes were known to the early Egyptians, and were used by them with great ability before the commencement of the Christian era.

As an example of the advance made in mechanical

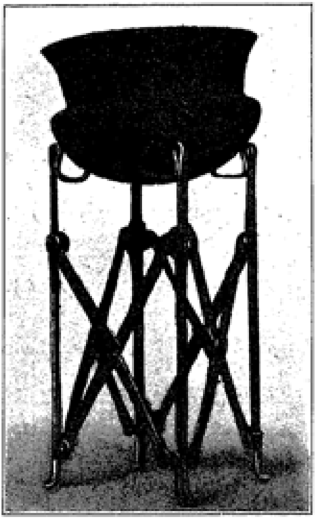

Fig. 37.—Collapsible Stand (Open).

constructions during Græco-Roman times, the stand shown in Figs. 36 and 37 may be taken. This interesting piece of work, which may possibly have been made abroad and imported into Egypt during either the Ptolemaic

or Roman period, is a collapsible frame made of bent copper strips, and is still in working order, notwithstanding the somewhat corroded state of the metal. The photographs show the stand both closed and open. Here we have the origin of the collapsible frame furniture, which is so extensively used at the present time for camp use. The bowl shown was simply placed on the stand for photographing, and is not an adjunct to the stand.

Why it should have been considered necessary to make such a small stand (size about 4 by 6 inches) collapsible is not obvious, but most likely it was only a model intended for the equipment of a grave; there are much larger stands of this type in the Roman room of the British Museum.

As the earliest Egyptians, even up to Roman times, did not understand brazing or soldering, their methods of repairing metal articles were necessarily simple. The vase shown in Fig. 18 had a flaw when cast, which left a small hole in the side. This was plugged with a little rod of bronze hammered flat on the outside, but left penetrating inside the vessel, as shown in Fig. 19, as it was not accessible for hammering.

To meet suggestions which may be proffered that this rod was one of the struts used for holding the core during casting by the wax process, it may be said, firstly, that struts were quite unnecessary, as the vase was open top and bottom, thus allowing ample means for securing the core; secondly, that the rod was only ¼ inch long, and was tapered on the inside, obviously in order that it should securely fit the hole and make a water-tight seating for itself; and thirdly, and chiefly, that the metal of the vase immediately round the plug was burred over into the interior just as the tapered rod had left it when forced into position.

As the bottom of the vase, as well as that of a second similar vessel of the same period, was fixed in place by similar means, it may be taken as being one of the methods of construction and repair in vogue at the time.

Another method of repairing flaws, which has previously been alluded to, was applied to the bronze Roman pot in Fig. 38. This vessel had three repairs, each consisting of flaws that were closed by running molten metal into them. That they were flaws in manufacture is shown by the fact that the alloy

Fig. 38.—Roman Pot.

Fig. 39.—Repairs in Roman Pot.

used for the repair is the same as that of the body. We may perhaps assume that this method of repair was used because the fault occurred in the foundry, and not subsequently during use of the article.

A photograph of two of the repairs as seen from the inside of the pot appears in Fig. 39.

It became a general practice with the early Egyptians to make an addition of lead to the bronze used for casting ornamental and devotional objects. Whether this was done to economise copper and tin, or to produce a pleasing patina, is not known, but they seem to have learnt that a proportion of lead (in some examples it reaches 33 per cent.) simplified casting, made the metal softer for chasing and engraving, and that for ornamental objects it was not objectionable. On the other hand, in antique Egyptian implements we do not find lead except as an accidental impurity in trifling amounts.

It should be borne in mind that the statuettes, of which numbers exist in our museums, are chiefly those of gods and sacred animals used as votive offerings. They were placed in temples and in houses to ensure the protection of the gods. This being so, they may be regarded as objects of a purely ornamental nature, and it would not be essential that the metal should be pure or possessed of any great strength. We find that they were generally made of very poor metal, and in some cases obviously cast from scrap metal.

The bronze used for portrait statues and statuettes of kings and high officials seems, from its external appearance, to be of much better quality (as also is the workmanship) than that of the religious statuettes. The metal is harder and more yellow, thus indicating a higher proportion of tin and less lead, but analyses have rarely been made, and specimens never fall into the hands of the investigator because of their value as relics.

It may be mentioned that the guides and other publications issued by museum authorities are not always quite careful in distinguishing between copper and bronze; there are several instances in which objects are described as copper in one work and bronze in

another. The errors are due probably to the fact that the statements are not always based on chemical analyses. This point is occasionally of some importance.

As an instance, we may take a well-known specimen belonging to the xth Dynasty, generally alluded to as the Brazier of Khety, and now in the Louvre. In the catalogue of the British Museum it is spoken of as a bronze bowl, whilst Professor F. Petrie, in his *History of Egypt*, calls it "copper open work of a brazier or some round object."

It has often been asserted that the ancient Egyptians used for their bronze an identical percentage of tin to that used at the present day, but this statement, though near the truth in some respects, needs some qualification.

It may be taken for granted that they found an addition of tin over a certain percentage produced a brittle, unworkable alloy which would be quite useless to them for most purposes.

At the present time bronzes for different purposes are made of varying proportions of the two constituent metals, and, also, additions of other metals are made in small amounts to render the working of the metal easier, and to produce other desirable results. The bronze alloys in use to-day for mechanical purposes do not contain more than 12 per cent. of tin, and this proportion we do not find exceeded in the old Egyptian bronze objects intended for similar uses.

It seems very probable that bronze was first used for ornamental work, because the early Egyptians found its colour more pleasing than that of copper, approaching, as it does, the colour of gold. It is almost certain that tin was much more expensive than copper to them, and no added hardness would be required in such objects.

For many years it was supposed that the ancient

Egyptians had some secret means of hardening copper and bronze which has since been lost, because, as only tools of these metals had been discovered on ancient sites, no other means remained of explaining how the magnificent works in hard stone were produced during the earlier dynasties.

In Chapter V. will be found the microscopical evidence which proves that no secret or other hardening processes could have been used, but we may consider here some of the factors which may have conferred additional hardness upon the copper and bronze made in the old Egyptian foundries.

It is obvious that for the working of wood and the softer stones no special hardening of the metal tools would be called for. The increase of hardness conferred by hammering the cutting edge of the tool in the cold state would suffice; but for such hard stones as to-day require the best steel tools for their manipulation, it cannot be agreed that hammered bronze or copper would do; in fact, experiments made by the author have conclusively proved otherwise.

A method of increasing the hardness of copper is to make an addition of another metal, such as iron, arsenic, nickel, etc., but although these are found in old specimens of tools in small amounts either as impurities or ingredients (more probably the former), they cannot have conferred sufficient hardness for the special purpose above mentioned, and it may be added that the hardening effects of these metals must have been much modified by the presence of other impurities, such as bismuth, lead, and cuprous oxide, which are invariably found, separately or collectively, in old specimens of tools. Bismuth, than which there is no more harmful impurity in copper, occurs in many of the analyses which have

been carefully made of copper tools, and it is impossible that chisels of such impure metal, with its inherent brittleness, could have been of the slightest use in the chiselling of hard stone. It is certain that, even supposing a cutting edge could be prepared on such chisels sufficiently hard for use on hard stone, it would not even stand the shock of the blows in carving.

An interesting tradition that was mentioned to the author by the late Sir Gaston Maspero, the famous director of Egyptian antiquities, relates that antique copper was hardened by heating the metal and then quenching in the blood of oxen. We know, of course, that such treatment would be much more likely to soften the metal than to harden it. It would seem a method much more likely to have been applied to steel.

The idea of secret hardening processes for copper and bronze formerly entertained by archæologists is, however, now held by only a few, but is superseded by other theories of a more plebeian, but not more feasible, nature. These are dealt with in a later chapter, and we may say definitely and finally that the ancient Egyptian metallurgists knew nothing about these two metals that we do not know to-day.

The latest researches show that the hardness of certain bronzes may be modified by carefully applied heat treatment, but the range in variation is not great, and as modern apparatus for governing the temperatures is absolutely necessary, the method would not be available to the ancients.

There is, however, little need to spend time endeavouring to find out hardening processes that might have been applied to bronze, because works in hard stone were carved during the extensive lapse of time prior to the

introduction of tin into Egypt, and, therefore, the question is limited to the hardening of copper.

With regard to the presence of arsenic in antique Egyptian copper, archæologists have stated that the arsenic was no doubt intentionally added as a hardener. This statement is impossible to prove, and there are many arguments in favour of the view that its presence is more likely to have been accidental. Firstly, it may be said that the hardening properties of arsenic are of a low order, and are much below those of other metals almost invariably present, as impurities, in these old specimens, as, for instance, iron, tin, and nickel.

From the ferruginous flux used in smelting, the copper would take up sufficient iron to confer far more hardness than arsenic was capable of producing. Secondly, there is no regularity in the amounts of arsenic found in different specimens (varying from ·02 to 4 per cent.), and arsenic is found in articles for which the essential property would be softness and not hardness. Thirdly, arsenic is such a common impurity of copper that no further explanation seems necessary to account for its presence in old specimens.

The argument put forward to support the intentional addition of arsenic theory is merely that arsenic has not been found in the few specimens of local cupriferous ores that have been analysed, nor in the ferruginous sands used as fluxes. From the mere fact that some of the copper articles contain arsenic and others do not, it has been deduced that the Egyptians knew how to modify the hardness of their metal. To support this, the arsenic content would need to be fairly regular, and would not be found in articles for which maximum softness would be essential. It seems just as possible that copper from some localities contains arsenic, obtained

either from the ore, the flux, or otherwise in the smelting, whilst copper from other localities was not so contaminated. In any case there is always the possibility that certain ores or fluxes have been worked out, and that the samples analysed have not been properly representative.

Unfortunately, there are no contemporary records, such as tomb paintings and so on, showing the method of making and working bronze in early Egypt, and so we are compelled to rely upon the evidence of the finished articles that are retrieved from the earth, and upon the information that the latest developments of metallurgical science enables us to deduce from them.

In the Cairo Museum there is a limestone relief showing jewellers melting gold, and we assume that similar methods were employed for bronze.

An old Egyptian crucible was found at Serabit in Sinai, and was similar in shape to the bowl of a tobacco pipe, with a hole in the side for pouring; of what material it was made is not recorded.

An old copper smelting furnace was also found in the Sinai Peninsula by Mr. C. T. Currelly, M.A. It comprised a hole in the ground about 30 inches deep, round which a circular wall was built having two holes for tuyeres, one 15 inches higher than the other. The fuel used for all foundry purposes in ancient Egypt must have been charcoal.

The production of copper ore at the mines, its reduction to metal, and the manufacture and working of bronze, must have been an industry of considerable magnitude, but whereas we have of the coeval craft of stone-working, a fair show of statues, temples, and other large productions, for all the quarrying that was done in various parts of the country, we have practically nothing of importance to show to-day for all the metal that was

6

mined, won by conquest, and received in trading operations. One life-size statue, several parts of what were presumably complete life-size pieces originally, several about half life-size, and a few portrait statuettes, are all the creditable productions that careful and continuous excavations have brought to light; and if we add to them the hundreds of little statuettes and minor articles, chiefly of insignificant workmanship, the total must still bear an infinitesimal relation to the actual original output.

The explanation lies more in the secondary value of the articles as metal, and in the number of revolutions and changes of rulers that the country experienced, than in the perishable nature of the metal or actual losses through the march of ages.

Even during the Greek and Roman periods there must have been many large bronze statues in Egypt, for they attracted the notice of Greek visitors. Plutarch in his Theosophical essays describes some of them, and is at great pains to endeavour to account for the pleasing blue colour which they are said to have possessed. Whilst this patina must necessarily have been in a great measure due to the composition of the bronze itself, not improbably containing gold, the effect was further enhanced by a coating of oil which was applied to the surface.

It is most unfortunate that the majority of bronze articles that have been found cannot be assigned to any period with certainty. Very few bear inscriptions, and the number found on old sites along with antiquities of other kinds that can be dated, is small. Most of the specimens seem to be discovered by natives who assiduously turn over the sand in likely places for such small articles, and as these persons are often not desirous of letting the authorities into their secrets, even the locality from which a specimen comes, is not disclosed.

Amongst archaeologists it is the practice to assign to any non-ferrous metal object not found under known and convincing circumstances or not bearing marks by which they may be dated, or not ostensibly prehistoric, Greek or Roman in design, to the Saitic period, generally the xxvith Dynasty.

The number of bronzes that are found in Egypt is, however, diminishing. In former times they were not uncommon, and the draining of the Lake of Karnak at Luxor provided almost a glut of certain varieties, but they are becoming scarce and consequently very expensive.

The statuettes, tools, and other small objects, of which we possess such numbers, are very useful for scientific investigations, as well as for enabling us to form some idea of the decorative side of Egyptian metal work, and of its application, but they do not, of course, enable us to estimate the magnitude, nor the refinements of early founding, as would large specimens that could be regarded as *chefs d'œuvres* of the craft. It is certain that, unlike the huge and wonderful stone monuments, which had little or no intrinsic value to subsequent rulers and races, copper and bronze work went wholly into the melting pot during or following revolutions, wars, and times of national need.

When we reflect that from a state of ignorance the ancient Egyptian metallurgists evolved the foundations of an industry which was to have astounding influence upon the world's civilisation, we can appreciate the patience, skill, and determination with which they must have carried out experimental and even research work.

Did we but know them, we might with justice remember the names of the first inventors amongst those primitive people, of double moulds, of the waste wax casting process, of "cored" castings, and of glazing and

enamelling, along with those of their successors in the craft of metal-working of modern times, who discovered aluminium, electrolytic reduction of metals, and other similar advancements in metallurgical science and handicraft. To us, the first quoted inventions may seem now somewhat trivial ones as compared with the others, but we should bear in mind that, whereas modern improvements are the outcome of progressive advancement in practice and theory over a course of fifty centuries, the first Egyptian workers had no such ladder of learning to assist them, but started from a basis of absolute ignorance.

The fondness that the ancient Egyptians acquired for copper utensils in the remote days of antiquity still survives in Egypt to-day. The poorest native prefers his stew pot to be of this metal in preference to the more economical cast iron now in general use elsewhere, for he knows copper vessels always have an intrinsic value, and to him they act as a sort of bank, just as some of his more flourishing countrymen load their women with gold jewellery, buying and selling it as changes in circumstances dictate.

Mention should be made of a secondary use that was made of metals in the form of their oxides for producing glazes, enamels, coloured glass, and paints. Blue glazes were applied to pottery even in prehistoric days, and subsequently green, violet, black, red, and white ones from the oxides of copper, cobalt, manganese, iron, and tin.

We also find that metals and their oxides were included in medical prescriptions, as, for instance, a remedy for inflammation of the eye, which was made up of myrrh, white oil, antimony, and oxide of copper, together with other items of more or less medicinal or toxic value.

CHAPTER III.

THE IRON AGE IN EGYPT.

There is no doubt whatever that iron in its metallic form was known in Egypt at least as far back as the IVth Dynasty; indeed, it would be somewhat difficult of explanation had it been otherwise, seeing that, at that time, another metal far more difficult to obtain from its ores (copper) was being extensively produced, and that iron itself, in the form of hæmatite, occurred in much greater quantity than copper.

Surface ores no doubt existed in abundance; articles such as head rests, beads, and statuettes carved from hæmatite, which have been found on old sites, tend to prove this.

There are to-day considerable deposits of hæmatite in the southern and south-eastern portions of Sinai Peninsular, and in certain parts of Egypt, such as the north-eastern and south-eastern deserts, besides red and brown ochres and ferruginous sandstones. Readers interested in the actual sites of present iron ore in Egypt are referred to an authentic paper, entitled "The Distribution of Iron Ores in Egypt," by Dr. W. F. Hume, Director of the Egyptian Geological Survey.

Old iron workings occur at Wadi Abu Jerida in the north-eastern desert, but these are thought to be Roman. It may well have been, however, that the Romans were merely the last people to work them.

The date of the commencement of the iron age in

Egypt is perennially discussed, and unfortunately but little fresh evidence comes along as time progresses.

An apology is needed for introducing matters of a somewhat polemical nature into a practical work as this is intended mainly to be, but polemics are almost inseparable from archæology, and, as the subject is intimately associated with the beginnings of the metal worker's craft, a plain statement of the two sides of the argument, from a metallurgical standpoint, is not outside the scope of the book, as the practical man will thereby be enabled to give his opinion on an interesting problem which has not hitherto been so fully presented to him.

Readers should bear in mind, however, that some of the archæological evidence is, of necessity, exceedingly slender, especially much that is based upon the works of such academic writers as Pliny, Homer, and Plutarch. Further, on almost every important question, archæologists of repute hold opposite views, and whilst the majority appear to favour the date of 1000 B.C. for the first application of iron in Egypt, several, including Dr. Budge, of the British Museum, are inclined to believe that the metal was used much earlier.

As iron is far less workable than copper and most other metals, difficulties in working may have limited its application when it was first introduced. Also, seeing that it must be worked hot, and handled hammers were unknown at the time, it is quite within the bounds of possibility that the men skilled in its manipulation were, for a considerable period, few in number.

Some writers have suggested that the paucity of antique iron objects in Egypt may be due to the fact that iron existed in a native state in pockets, and that these being discovered only occasionally, only a small

number of articles could be made. But there is little need of this explanation, as the oxides of iron are so readily reduced.

This scarcity of iron objects, even in the later periods, has never been satisfactorily explained by archæologists; they content themselves with a definite statement, argued largely from the history of other ancient countries, that iron was not in common use until about 1000 B.C., and they offer no satisfactory explanation concerning the several iron articles of authentic origin that have come to light from periods anterior to that date by centuries.

We know that throughout the historical period of ancient Egypt, magnificent sculptures and other works in the hardest of stones, such as diorite, basalt, and granite, were executed with consummate skill. In the IVth Dynasty, especially, many statues in diorite, the most intractable of stones, were carved, and even bronze tools were not then available, because tin had not been introduced into Egypt by that time.

A photograph of one of the finest examples in diorite of the IVth Dynasty is given in Fig. 40. For purposes of comparison an illustration is also given in Fig. 41 of a splendidly chiselled statue in grey granite, belonging to the XVIIIth Dynasty (B.C. 1580-1350), which was, therefore, made about 400 years after the date sometimes ascribed to the commencement of the common use of iron in Egypt. No great difference in the execution of the two works strikes the eye, and yet we are invited to believe that two very different methods of cutting and carving were used upon them.

It is important to remember that the fashioning of a statue or other artistic production in stone entails several different operations. First, there is the cutting

of the block from the rock in the quarry, which may be done by any method of sawing, or cracking by fire, or by breaking by means of wedges; secondly, there is the

Fig. 40.—Statue in Diorite. IVth Dynasty. Specimen of Earliest Hard Stone Work.

Fig. 41.—Statue in Grey Granite. XVIIIth Dynasty.

roughing out done by breaking off large lumps of the stone by hammers. Thirdly, and this is the only process which need concern us in considering the necessity for iron tools, there is the final careful shaping and the cutting of detail followed by polishing.

The following is a list of some of the iron objects belonging to periods prior to 1000 B.C. that have been found in Egypt :—

Iron tool from the Great Pyramid of Khufu at Gizeh, ...	IVth Dynasty,	2900 B.C.,
Fragments of iron picks from the Black Pyramid at Abusir, . . .	Vth Dynasty,	2700 B.C.
Mass of iron rust from Abydos, . .	VIth Dynasty,	2500 B.C.
Iron spear head from Nubia, . .	XIIth Dynasty,	1750 B.C.
Iron sickle from beneath a sphinx of Horemheb near Karnak, . .	XVIIIth Dynasty,	1450 B.C.

In addition to these, there are beads of iron belonging to prehistoric times, of which Gowland reported that they consisted of hydrated ferric oxide of the following composition :—

Ferric oxide, . . .	78·7 per cent.
Combined water with traces of CO_2 and earthy matter,	21·3 „
	100·0 per cent.

These beads consisted of iron rust, none of the original iron having escaped oxidation. They did not consist of iron ore, but of hydrated ferric oxide, the result of the rusting of wrought iron, of which they were originally made. These beads were made from thin bent plates.

It should be stated that on some of the finds in the above list doubt is cast by certain archæologists as to the authenticity of the site upon which they were discovered, but here again we have one expert against

another, and it would really appear that some of these experts are prepared to swear to the provenance of, and to accept without demur, only those objects that they have personally unearthed.

The discoveries are indeed fragmentary, but they certainly seem to show that the working of iron was well understood almost from the beginning of historic times.

With regard to the early specimens mentioned above, Gowland considered that the first specimen, found during blasting operations within the Great Pyramid of Khufu at Gizeh in 1837, was not a natural terrestrial product, and suggested that it was "not altogether impossible that it came from the Sinaitic Peninsular, and was obtained there by the accidental treatment by the copper smelters, of the rich iron ore which outcrops near the vein of copper ore."

The fragments of iron picks from the Black Pyramid at Abusir were found by Maspero in 1882.

The mass of iron rust from Abydos, apparently from a wedge of iron, was found by Petrie himself, stuck together with copper adzes of the VIth Dynasty type, at the level of floors of that age in the early temple of Abydos.

The specimens enumerated are wrought iron, and they indicate that the production of this metal and its manipulation must have been well understood. Neglecting the small prehistoric beads, and considering the next earliest specimen, that of the plate from the Great Pyramid, it may be said that its size and its state of finish show indisputably that it was not amongst the first efforts of the Egyptians in the production of iron articles, and, therefore, the first working of iron must surely have taken place some time previous to the IVth Dynasty. These facts dispose also of another argument that has

been put forward to the effect that the ancients, prior to B.C. 1200, knew only of iron as a curiosity. It is unthinkable that they would be content to let iron remain to them a curiosity when they were experts at getting and working at least three other metals. On the other hand, it is quite likely that iron articles were scarce and expensive, and that only comparatively few persons were skilled in making them. It is not impossible that in its early days iron was only used for those purposes which no other substance could be made to serve. And if we look at it in this light, we may conclude that almost the sole purpose, in primitive times, which no other material would fulfil satisfactorily, would be the chiselling of hard stones.

If, as many archæologists assert confidently, iron tools were not available in Egypt prior to B.C. 1200, no other implements but those of copper could have been used for the superb works of the IVth Dynasty, and bronze ones probably after the VIth. The idea that secret processes for hardening the two latter metals were known to the ancients has already been dismissed, and further conclusive evidence will be found in the chapter on the Metallography of Antique Metals, but we may now briefly review some of the later theories that have been put forward to explain how the ancients were able to turn out such fine examples of the sculptor's craft with tools of copper or bronze.

It is obvious to the metallurgist that the sculpturing of granite and similar materials could not have been done with copper chisels, and although bronze ones might give slightly more satisfactory results, we are saved the necessity of considering their possibilities, as there is a period during which hard stone was sculptured of at least 1,000 years before bronze was known.

The copper tools that have been found would, of course, be quite useful against limestone and other soft stones, which were much used for sculpture and building during all periods.

Professor Flinders Petrie has stated that sawing, cutting, and some forms of sculpturing in hard stone were done by copper saws and chisels in which emery points were embedded. In fact, he even found part of such a saw, but as he found it in Greece, and not in Egypt, and as it was embedded in limestone, not diorite, the discovery is not very convincing. There is apparently no positive evidence that saws of this kind were used for diorite and granite.

Another solution has been put forward in recent years. According to this, the stone is supposed to have been roughly shaped by suitable tapping with a stone hammer, and afterwards the surface was ground to shape with emery. This method could not possibly have been applied to the cutting of sunk reliefs, or, for instance, to the scooping out of a sarcophagus in such a stone as red granite. These stone coffins were made from one piece of granite or diorite, and measured approximately 1 yard high by 1 yard wide, and 2 yards long, and were hollowed out, leaving walls about 6 inches thick, perfectly straight, well dressed, and square.

According to Professor Flinders Petrie, a somewhat fantastic method was used for the carving of large hieroglyphs. The cutting, he says, was done by copper blades fed with emery and sawn along the outline by hand; the block between the cuts was broken out by hammering and the floor of the sign was hammer-dressed (stone hammers), and finally ground down by emery. A photograph (Fig. 42) shows the varied forms which these hieroglyphics assume, and the reader will no doubt

agree with the author in wondering how the method described could be applied to the carving of a small sunk circle or to some figure with irregularly curved sides. The figure is a photograph of the writing on the apex stone of black granite from a XIIth Dynasty pyramid at Dashor. The workmanship is exquisite, and the perfection of the cutting is difficult to reproduce photographically, but the illustration shows the variations of form that were used in the old writings, and how clearly their lines and angles are chiselled in the hard black granite.

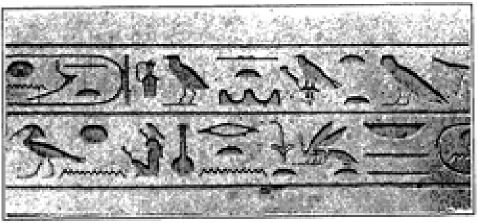

Fig. 42.—Pyramid Hieroglyphics in Black Granite. XIIth Dynasty.

If the emery-fed copper-blade method was used for cutting out hieroglyphs, it would mean that the statue or other object would need to be rolled over and turned about so that each surface to be carved could be laid horizontal during the cutting, to ensure that the emery would remain in the groove. We can hardly conceive that after a piece of sculpture had been finished by the artist in its erect or natural position, he would relish the risk of damage to his masterpiece that would be incurred by this method.

If any special methods of tapping or grinding such as

these had ever been in general use, it is not unlikely that some survival would be found in the existing customs and crafts of the country, but there is none. In other trades to-day we find implements of types which can be traced back to the earliest times: the primitive plough, the bow drill, the carpenter's adze, the needle—all these may be seen in daily use in Egypt differing in no essential respect from those used by the ancient Egyptians, as shown in the mural decorations and exemplified in the specimens in our museums.

Even now diamonds are sometimes sawn by an iron wire held in a frame and fed with diamond dust, and other instances might be quoted where a comparatively soft material is used to cut through a harder one with the aid of an abrasive agent. For instance, the mild steel chamber of a rifle barrel is often worn away by the constant rubbing of the cord used in cleaning the bore, but the actual cutting must be attributed to particles of grit which are held by the more or less greasy cord. Each of these two processes has its own particular points. They are both extremely slow in action, and are much more erosive to the softer material used for conveying the pressure (the iron wire or the cord as the case may be) than they are to the diamond and the steel barrel. A consideration of these processes would seem to give support to the idea that a copper-emery process of cutting might have been used by the first Egyptians, but the author has proved by experiment the impossibility of cutting granite or diorite by any means similar to this. By the use of emery powder, anointed with oil or turpentine, no measurable progress could be made on the stone, whilst the edge of the copper blade was rapidly worn away and rendered useless, the bottom and sides of the groove being coated with particles of

copper. For some of these experiments a start was made by sawing a small groove with a steel saw, whilst for others an attempt, devoid of satisfactory results, was made to start a way for the copper blade by scratching with a flint point, as it was thought that the latter might have been a method employed by the ancients, and it was quite impossible to start a passage way with the copper tool itself.

The author strongly begs all those who think the Egyptians used such a process of cutting, to try it. Even with our modern copper and well prepared emery of uniform grain-size, the results are, to say the least, disheartening.

It is worthy of remark that a process of this kind would certainly leave much copper on the sides and in the grooves in which it had been used, and that, therefore, traces of green discoloration due to verdigris, might conceivably be detected in recesses where the polishing of the stone had not penetrated, but none of the finished or unfinished sculptures in our leading museums shows any such signs.

The reader is invited to ponder over the difficulties of a person endeavouring to carve, in diorite, a rock of almost steely hardness, by means of a copper blade held in the hand and traced round the outline along with emery grains, a cleanly cut figure of the pattern shown in Fig. 42, with the sides and bottom perfectly flat and corners sharp.

It has never been stated by supporters of this method that they do not believe it continued in use after the use of iron became general: presumably, therefore, they consider it did, because there would be no reason to supersede a process that had proved capable of turning out the admirable results displayed by the earlier works.

There is no such survival of any of these freak processes for the sculpturing of hard stone. On the contrary, the makers of fraudulent granite statues, who live in Southern Egypt and execute fairly creditable copies for the unwary and affluent tourist, and who may or may not be able to trace back their descent from their worthy predecessors whose masterpieces they imitate, do their sculpturing by means of iron chisels of poor quality. These shady businesses pass from father to son: there is a certain amount of art and skill inherited, besides no doubt a fair admixture of cunning, and they would be just the directions in which to search for survivals of old and particularly serviceable stone-working methods.

Many of the antique Egyptian statues are perfect examples of the sculptor's art; the hardest stones were carved and shaped with unfailing accuracy, faultless symmetry and definition: sharp corners with perfect angles and knife-like edges, gracefully curved and plumb straight lines, grooves and serrations: deep and shallow depressions and reliefs, with delicate, undulating contours, or rigidly plane surfaces. To observe all these, together with the exquisite tooling of the hieroglyphs, is to be convinced that there is one, and only one, way of obtaining such results, and that by the use of a chisel. Any rubbing process would surely have robbed the angles and corners of all sharpness.

Stone-masons' wooden mallets, exactly similar to the kind used at the present time, have been found in quite important numbers, and the weight of the evidence tends to indicate that stone carving was done just as we do it to-day.

It is not easy to understand the general reluctance on the part of archæologists to acknowledge the evidence afforded by the iron articles discovered in Egypt and attributed to the earlier dynasties, especially seeing that

some of them were brought to light by persons of eminence in archæological research, under conditions which admit of no doubt as to their authenticity. We have, up to about 1400 B.C., a list of five articles going back to the IVth Dynasty, precisely the dynasty when diorite was much used. It is true that these finds are few in number, but is it any more unreasonable to argue that iron tools were in use on the evidence of several discoveries, than it is to say that sculpturing was done by emery-pointed blades because one tool apparently of this nature has been found?

The paucity of iron objects may be due to their having perished. An eminent archæologist has previously characterised this statement as absurd, adding, at the same time, that nothing is more permanent and noticeable than iron rust. As to permanency we must all be quite in accord, but with regard to discernability, it may be said that in a soil permeated with chlorides like that of Egypt, iron will rust rapidly, and the resulting rust is likely to be extremely friable and readily disintegrated, because of the comparatively large percentage of soluble salts that are formed. The noticeability of iron rust will always depend upon its surroundings, and this point leads to the suggestion that the iron plate of the IVth Dynasty being found in the pyramid disproves any statement that early iron tools, if there were any, will by this date have perished. Is it not probable, however, that this particular piece of iron was only preserved because it was in the exceptional position described, and, secondly, would it have been so noticeable had it been buried in sand or earth? This specimen was between two stones inside the Pyramid, and was, therefore, in a very favourable place, not only for preservation, but for recognition also.

It may be assumed that, instead of being buried in chloridic soil, it was in something of a dry air chamber. These conditions must be regarded as exceptional ones, tending towards preservation.

The untoward property of rusting that iron possesses is known to all, and the merest tyro is aware that the rate of rusting depends upon the situation. Therefore, arguments which are perfectly sound with respect to Europe may not apply to Egypt. Antiquities, especially those of iron, have seldom or never been exposed to the atmosphere during their existence, but are recovered from the ground, where they have been buried, in positions more or less saturated with moisture, and with corrosive salts, for hundreds of centuries, and in Egypt it is only articles of a very heavy nature that could survive such treatment.

The author has examined several iron objects found in this country. Two small bronze bells of the Græco-Roman period, each of which had an iron striker, showed in a clear manner the marked difference in the rate of oxidation of the two different metals. Whilst the bronze was in good condition, metallic, and only slightly coated with a green crust, thus proving that the bells had not been lying in an abnormally bad position from the point of view of preservation, the iron strikers, which were made of wire about $\frac{1}{8}$ inch diameter, were completely rusted to oxide, and were lying inside the bells in the form of a string of powder, which fell away at the slightest touch. Had these pieces of iron been outside, instead of in their protected positions inside the bells, they would have disappeared ages ago, and there would have been no signs to-day that the bells ever had iron strikers.

In specimens of cored bronze castings, belonging to times older than the Roman period, having iron struts,

the author has always found the iron completely oxidised, even where it passed through the bronze, which itself was well preserved, whilst in the material of the core the swollen and diffused mass of rust could only be detected with much difficulty.

A striking instance of the difference in the rate of rusting of iron came to the author's notice at Alexandria. Along the Egyptian northern coast are certain large iron guns, which have lain unused now for about 40 years. At one fort, facing the sea, where they are exposed to the sea breezes and, no doubt, on occasion, to spray, the guns have now a coating of oxide from $\frac{1}{8}$ inch to $\frac{1}{2}$ inch in thickness, which is gradually falling off. In the progress of time, these guns, if untouched, will cease to exist, and nothing, except a richness in iron of the surrounding sand (detectable by chemical analysis alone) will remain to show that any iron article ever existed in the vicinity.

In contradistinction to this, there is another fort only half a mile away, but overlooking one of the branches of the Nile delta, where the guns are still in a remarkably good state of preservation, and the coating of rust on them, after 40 years, is unmeasurable.

It is highly improbable that the authentic iron specimen (now rust) of the VIth Dynasty would have been preserved had it not been wrapped in fabric with some other articles. This specimen can be seen in the British Museum, and whilst it is likely that it was originally an implement of some sort, seeing that it was wrapped with others of copper or bronze, it now exists merely as an unshapely mass of rust.

Excavators are too apt to expect antique iron objects in Egypt to resemble in appearance those belonging to the early iron age of Europe, and they probably overlook the fact that in Egypt, if we only go as far back as the

period of the first authentic specimen—*i.e.*, the IVth Dynasty—we are dealing with periods anterior to that age by about two thousand years, which means that the objects would be nearly twice as old as the earliest specimens found elsewhere. It does not seem extravagant therefore to assume that the earliest iron objects of Egypt have perished.

It should not be forgotten, when speaking of the scarceness of iron antiquities, that ancient copper and bronze articles, especially tools, are also scarce in relation to the vast numbers that must have been made and used in ancient Egypt.

Another point emphasised by those holding views against the early use of iron in Egypt is the fact that the iron age in Europe generally did not begin before 1000 B.C. For instance, Mr. H. B. Walters, in his general review of the bronze and iron ages, contained in the Catalogue of Bronzes of the British Museum, says that the date of introduction of iron working varies in different parts of the world, but nowhere can evidence for its appearance be got earlier than 1000 B.C. Supporters of these views then go on to deduce that, had iron been in common use in Egypt previous to that date, it would surely have been introduced into neighbouring countries. In answer to this argument, it may be stated that supporters of an earlier date for the iron age in Egypt do not claim that the metal was used extensively, but merely that it was comparatively rare and used only for a few special purposes; and to this it may be added that in Egypt, even after the date of the beginning of the iron age in Europe, as, for instance, during the extensive use of the metal in Syria (to which country many ascribe the first use of the metal), Egyptian iron antiquities are still extremely scarce, and this would appear

to indicate either that iron was not imported into Egypt in great quantities, or, supposing it were, that the rapid deterioration of the metal in Egyptian soil is a sufficient explanation of the rarity of the discoveries on its ancient sites.

Mr. Walters further says—"The only argument that can be urged on the side that iron was known and used by the earliest peoples is that it is more perishable than bronze. In answer to this," he continues, "it is only necessary to point out that in the later tombs it has been found sufficiently often and in sufficient quantities to refute such a hypothesis."

This may be true of Greece, but with regard to Egypt it cannot be agreed that iron has been found in later graves in quantities sufficient to show that its rate of deterioration cannot account for its paucity, and it must be remembered that there are no Greek works of sculpture in hard stone of a date so remote as that of the IVth Egyptian Dynasty. So far as the author is aware, there is no other part of the world of which the history and the early culture demand an iron age prior to 1000 B.C. There are no works in hard stone and no cored castings (requiring iron struts) from European and Eastern Asiatic countries of periods coeval with the first four dynasties of Egypt. The absence of iron implements and weapons on early sites in Europe, therefore, does not affect the question with respect to Egypt. Moreover, it is not strange that, supposing the Egyptians did use iron a long time prior to B.C. 1000, other countries with whom they associated did not take it up, because the state of civilisation of the latter was not sufficiently advanced to require and work it.

Another factor affecting the number of iron specimens would probably be the religious objections of the Egyptians to the metal. The majority of antique objects found

in Egypt are recovered from tombs, and as the religion of the time was against iron, no articles made of it would be placed in them, and thus the sources that yield the bulk of our articles in copper, bronze, wood, and other materials, do not give us iron ones.

With the exception of the prehistoric beads previously described, no iron forms part of any jewellery : no doubt its property of rusting quickly turned the ancients against the use of it for such purposes, and this quite probably formed the foundations of the religious proscription. We find these objections carried on into Biblical times.

The iron tools first made would be extremely valuable to sculptors, and, no doubt, they would be resharpened time after time until they were too small for further use, after which they would be incorporated with other fresh metal by welding and used again.

The absence of iron fittings such as door hinges and similar articles seems to be sufficiently explained by the difficulties the first workers would experience in making anything except articles of a very plain form. Especially would this be the case if handled hammers were not used as archæologists affirm. Copper and bronze were always available in abundance for such purposes, and in addition were readily cast or worked to any required shape. Articles of this nature could not be made from iron until the iron workers' craft was well advanced.

Advocates of the later date for iron working in Egypt take as a further support the fact that on the old tomb walls, monuments, etc., there are no scenes depicting the making of iron ; but in reply to that it is only necessary to mention that there are also none of the making of bronze, and none of the manufacture of copper articles. These omissions are certainly strange, seeing that almost every craft except those of founding and metal working

is described or illustrated by reliefs or models placed in the tombs.

There are certainly two reliefs in the Museum at Florence which are said to show early iron-working. The origin of these reliefs is, however, very questionable; they bear only a slight resemblance to Egyptian reliefs, and they are absolutely undated. If they did prove to be Egyptian, they would certainly be of a comparatively late period.

Further, it is well known that the Egyptians had a word in their language for iron, for it was supposed to be the celestial metal of which the sky was made, so called possibly because of the fact that meteorites fell from the sky.

Iron and steel articles have been identified in certain Egyptian carvings, by their being coloured blue. It has been said that copper was always painted red, gold yellow, and silver white, and that iron was, therefore, meant when weapons and other similar articles were painted blue.

Prior to the IVth Dynasty the specimens of hard stone carving are rather scarce, but there are some well executed works in red granite, as, for instance, a column of the IIIrd Dynasty. The finish of these examples does not, however, compare with that of the work turned out in the IVth Dynasty and later.

About the time of the Ist Dynasty the sculptures in granite, though well proportioned, lack detail, whilst the finish of the prehistoric specimens is crude.

The gradual improvement in the working out of the detail and in the finishing of hard stone must have been due to the advances in tool making. The archaic specimens, which are chiefly reliefs, show traces of bruising and scratching as a result of the cutting away,

and have little or no fine detail that might have been carved with chisels. It is quite likely that the bruising was done with stone hammers and the scratching by flints, but the latter material would be useless as chisels because of the ease with which it fragments when struck.

The magnificent works of the IVth Dynasty and many of those of the IIIrd do not exhibit these peculiarities, and, therefore, the whole question of tools, or, to be precise, chisels, centres on these.

To the practical man there really seem to be few *a priori* reasons for refusing to credit the Egyptians with the first use of iron tools. They were first in many metallurgical improvements. As an instance we may quote "cored" bronze casting. This did not come into vogue in Greece until about B.C. 600, whereas in Egypt it was fully understood at least as far back as B.C. 3000, and probably earlier. The statue of Piupi is an example, but there are much earlier ones in the form of vessels with spouts.

It is worthy of notice that copper and bronze were used in Egypt for arrow tips up to Arab times. This is not easy to understand, unless it was because iron was scarce, and all supplies were needed for certain special purposes for which no other metal would serve, as these tips could so easily have been hammered into shape from wrought iron.

The author fully believes that iron chisels were in use by the IVth Dynasty. Archæologists point out that none has been found, but that copper and bronze ones have. It may be emphasised that the latter would be quite useful for soft stones, such as limestone, of which enormous quantities, far in excess of the quantities of diorite, granite, and similar materials, were worked during the whole history of the country.

It seems highly improbable that there were in vogue at the same time two different methods of stone working ; one (that of chiselling) for limestone and similar easily worked stones, and another, the suggested one of bruising, grinding, or sawing with copper blades, for very hard stones. Moreover, beyond some differences due to the texture of the stones themselves, there are no differences in the mode of finish of the sculpture in these two classes of stone, such as might have been expected had two different methods of working them been used. Some of the harder and coarser stones show a slight lack of sharpness in some of the finer details, but there is no difference in the general type and treatment. Hieroglyphs were cut with the same ease in each : the statues follow the same postures : the same truth to life and anatomical correctness appear in each.

A chisel for stone should possess an edge that is hard without being brittle. The hammering of copper increases the hardness, but it also renders the metal more brittle, and the harder metal can only be of use if it exists as a skin supported by unaltered metal. In a fine cutting edge this combination cannot be achieved. It has been said that, by hammering, copper can be made as hard as mild steel, but this can only be done at the expense of its toughness. Such a hard edge or point would be too brittle for use against hard stone, and it could only be produced on good copper. Even with our own hardened steel tools, the cutting edges require frequent sharpening, especially when used against hard materials, and in the carving of intricate work that might be compared with these statues of early Egypt, many chisels of different shapes are necessary.

Two minor uses for which iron would seem to have been of paramount necessity to the Egyptians long before

B.C. 1000 may be mentioned. Firstly, as struts for holding the cores when pouring bronze castings. In the preceding chapter we have seen that such struts were actually used although from the specimens examined it is impossible to say exactly how far back the use of iron struts dates. Secondly, as tools for engraving the detail on bronzes. Some of the inlaying and other ornamental work on hard bronzes (statuettes and statues) could not have been done without the aid of a metal tool very much harder than the bronze itself. Certain gravers with iron points that may have been used for this work have been discovered. But, unfortunately, there is no record as to what period they belong. The fact that the blades are fitted into bronze handles may indicate that iron was scarce.

It is strange that whilst in Syria iron was used for the weak parts of bronze castings—that is to say, the bronze was cast around an iron support—about B.C. 1000 (when iron was in general use in that country), we do not find iron used similarly in Egypt. This may be taken as a further proof, if one were needed, in support of the scarcity of iron in Egypt, though it need not be regarded as showing that the metal was not made such use of as the quantity of worked iron available admitted. It also indicates what has been previously suggested, that, in spite of the communication between Egypt and Syria, there was but little interchange of ideas and examples in iron-working.

Very primitive methods of reducing iron ores are still in use to-day in some parts of the world, and they give us a good idea of the simple means which may have been used by the ancient Egyptians. Mr. Grabham, the geologist to the Sudan Government, kindly gave the author the following particulars of a process which he

recently found in use by natives of the Southern Sudan :—"The smelting and smith work are carried on by the same man, but as more or less separate industries. When a native of the district desires a malot, he does not purchase it direct in one transaction from the ironmonger, but goes out into the bush, collects some iron ore, which exists in abundance in many places, and brings it to the smelter. The smelter provides the charcoal as part of his work, but the buyer has to stand by and help with the bellows while the iron is smelting. This work is done in a cone-shaped hut with the eaves reaching the ground, and without any proper door. Inside there is a hearth made of puddled mud with a hollow in the centre with positions for blowers but no raised structure. On one side of the hearth is a small basin in which some charcoal and ore are placed as an offering to the guardian spirit. The bottom of the pit is lined with grass, and on this is placed the 'twyer,' and above the mouth of the pipe is piled a mixture of charcoal and iron ore to a depth of about a foot. Having arranged the hearth and charged it, both the smelter and the buyer set to work and blow the bellows. The slag runs down among the grass below. The stalks are not burnt, but merely charred, and remain distinct in the slag which is discarded. The metallic iron is left as a spongy mass in front of the 'twyer,' and handed over at the end of the operation, either as it is, or beaten into a solid mass. The smelter, who also does the smithy work, uses the same blowers for both operations, but the two jobs are carried out in separate places."

"It is essential for the smithy to be near a good rock that can be used as an anvil. In this work he has a couple of assistants, who are experts in striking with the hammer stone. The buyer, having previously arranged for the

provision of charcoal, comes provided with some green sticks that are to serve as tongs in the manipulation of the iron. He takes a large share in blowing the fire, at which all natives seem to be experts, and the smith looks after the heating of the iron. One of the green sticks has been split and serves as a pair of tongs to remove the iron to the rock anvil. The beating is done with a large stone, which is raised above the head and brought down with full force in both hands on to the metal. The smith squats beside the metal, holds it in the tongs, and shows with the aid of a pointer where the next blow is to be struck."

"The most important use of the metal is, no doubt, for spears and malots, but excellent axes and adzes are made, and the iron is hard enough to take quite a good edge."

The process described is very similar to methods used in Japan and several other parts of the world until comparatively recent times, which have been fully described by Professor Gowland in his several works on the subject.

The ease with which metallic iron can be produced from its ores needs no comment here.

Egyptologists and others have given up the idea they held for many years that the reduction of iron ores needed extremely high temperatures besides elaborate furnaces, and, therefore, could not possibly have been in use in the earliest times. It is only the iron smelting, giving molten metal as a product, which calls for modern furnaces, but this process was never known in the days of antiquity either in Egypt or elsewhere.

Even in later times it would seem from the specimens that have been preserved, that iron was reserved for weapons, and tools for hard work, such as sculptors' and masons' chisels and adzes. In the Roman period in Egypt metal articles of an intricate or fancy nature

were necessarily made of bronze or brass, no doubt partly owing to the fact that the working of iron was not then completely mastered, and also possibly to the comparative scarcity of this metal, though, of course, the better appearance of bronze would alone recommend it for some purposes.

In stone work of our own times, there is a certain amount of roughing out done by breaking off pieces of the block by hammering and tapping, but for the final shaping and the dressing, chisels are a *sine qua non*, and these are employed in a great variety of shapes and sizes. It is with special consideration of the latter portion of the sculptor's work that the criticisms of suggested methods described in these pages are made. The criticisms refer not to the sawing of large blocks, or to the roughing out which may easily have been done with stone hammers alone, but to the careful and exact cutting out of recesses, such, for instance, as the eyes or the mouth of a statue, or to the precise tooling of hieroglyphs carved out of the stone with curves as free, sides as smooth and square, corners as sharp and correct, as many an artist might shape in clay.

Many unfinished Egyptian statues, and parts of finished ones not intended by the sculptor for public view, in all kinds of stone, granite, diorite, limestone, and others, show indisputably the marks or grooves left by the chisel. A photograph of some of these marks taken from a statue in the Cairo Museum is shown in Fig. 43.

The probable practical reasons why iron objects of early dynastic times have not been discovered may be recapitulated as follows :—

1. Iron was a rare metal, supplies not being abundant.

2. It was not used for decorative, religious, or symbolical purposes : it was not, therefore, placed in or used for making tombs.

3. It was essentially a useful metal, and tools, instead of being thrown away when worn, were re-made.

4. Iron rusts and disintegrates much faster than any other common metal.

Such is the evidence for and against the use of iron chisels in Egypt prior to B.C. 1000. Those archæologists

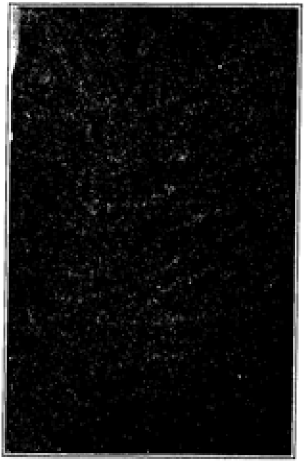

Fig. 43.—Chisel Marks on Hard Stone Statue.

who emphatically pronounce against it will probably never change their ideas unless some fresh indications come to light. They are obsessed with the importance of the archæological evidence on their side, negative in character as it mainly is, and they do not hesitate to credit early workers with skill and with a knowledge of

practices that we, with the progress of five thousand years behind us, cannot produce or apply to-day. The practical man can only term the alternative stone-cutting methods put forward by these experts as impossible ones. As to the contentions expressed in this book that the hard stone works of all the periods of Egypt, with the exception perhaps of some crudely executed ones of prehistoric and archaic times, were carved by means of chisels, and that the chisels could not possibly have been bronze or copper ones, the author believes that no further evidence is necessary, and that the stone worker and the metal worker of to-day will support his views.

The question of early iron may be taken a step further, and we may ask, supposing the Egyptians did use the metal as has been suggested, how far were they conversant with steel?

The advance from wrought iron to steel is not such a great one, nor is the conversion of the former into the latter a difficult operation requiring other than simple means. At the present time, much steel, under the name of cemented or blister steel, is made by heating iron in contact with charcoal, and this metal is used for cutlery, tools, etc., whilst the case-hardening of iron, an analogous process in many respects, is also in common use.

It may even be said that chisels of simple wrought iron would only be of little more use to the Egyptians than bronze ones against diorite and similar materials. Is it not quite possible that the Egyptian metallurgists discovered that by further heating the iron with charcoal, the fuel they used for primarily reducing the hæmatite, they could transform it into a much harder modification capable of taking a keen edge?

According to Professor Gowland, the iron plate from the Great Pyramid, on analysis, was found to contain

combined carbon, which tends to show that it was of a steely nature. Two other specimens of early iron that the author examined also proved to be steely, one of them being mild steel of quite good quality. The latter was a small cube, discovered amongst a collection of objects placed in the foundation of some old building, and every metallurgist will agree that the micrograph of a section given in Fig. 44 proves without doubt that it was mild steel. The other article was a wood chisel.

Even Professor Flinders Petrie admits that the case-

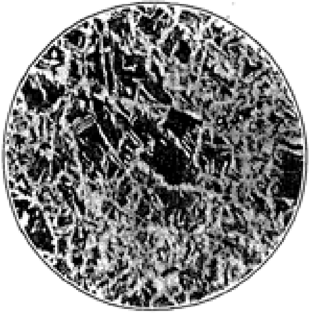

Fig. 44.—Photomicrograph of Cube of Mild Steel.

hardening of iron was known in Egypt before B.C. 666, for he says that the edges of certain tools, attributed approximately to that date, and found at Thebes, were of steel.

The author hopes that sooner or later the oldest specimens of iron now lying in various museums will be submitted to microscopic examination, so that the latest developments of metallurgical science may be applied to them. Provided a metallic core of any size remains in a sample, it should be easy to say whether it is iron or steel without in any way damaging the specimen.

CHAPTER IV.

ANCIENT EGYPTIAN TOOLS.

ALTHOUGH this chapter must be chiefly concerned with metal tools and tools for metal working, it is not proposed to exclude all reference to implements of other kinds.

The outstanding feature of many of the first tools is the persistence of type. In these cases, notwithstanding the advance of civilisation during five to seven thousand years, man has been unable to improve upon the patterns introduced by the Egyptians who designed them, and to-day we find tools and other implements identical in form and in the manner of their application with those of the early Egyptians.

The number of tools that have been preserved from the earlier periods is not large, especially when we reflect that a variety of artisans must have needed and used them. The number bears a low ratio to the quantity of works which must have been produced by means of such tools, and have come down to us. The carpenter, metal worker, jeweller, builder, and sculptor are all artisans who flourished from the earliest times of which we have records, and who would need substantial tools of metal.

There are some crafts of which we have no specimens of the tools used, but models, sometimes of workshops, and at others, of the tools themselves, have been found in tombs, whilst in other industries, the forms shown in the mural decorations of these structures are the only guide we have as to the kinds of tools employed.

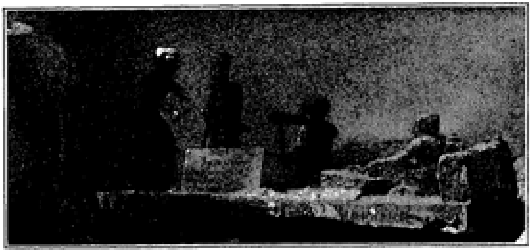

Fig. 45—Model of Carpenter's Shop.

Fig. 46.—Native using modern Bow Drill.

A photograph of a model of a carpenter's shop is given in Fig. 45. In this there is a double-handled copper saw, without teeth, but this omission was perhaps only made because the specimen was merely a model. Other saws that are in existence have serrated edges in a similar way to our own. The man in the centre is drilling with a bow drill made of a point of copper or bronze in a wooden handle, which is rotated by a bow: the string of the latter has perished. Here again the persistence of type appears: bow drills of this kind are used extensively in Egypt to-day, and a recent photograph of a native using one is given in Fig. 46.

Another tool of the carpenter that has continued in use during the whole of Egyptian history is the adze. This most useful tool, which serves as a chisel, axe, and hammer, is one of the modern Egyptian wood-worker's favourite tools.

A photograph showing it in use to-day is given in Fig. 47.

At first the adze was made of copper or bronze, but afterwards of iron. Specimens in both kinds of metal have been discovered.

The first metal blades for adzes were, in shape, merely copies of the co-existing flint ones, but as the knowledge of metal advanced, the shape became more adapted to the working properties of the metal, and it is said to be possible to form an idea of the period to which an early Egyptian adze belongs by the shape and style of the blade, just as a celt of prehistoric Europe may be roughly dated by its form.

The axe is an instrument that appears to have been one of the first made of metal, and it was used for war-like, as well as industrial, purposes. In prehistoric times the Egyptians made them of flint, and naturally the first

specimens they made in metal followed the flint type. It was merely a blade with two projections (Fig. 48), by means of which it was tied by leather thongs into a split stick. This implement, when used for splitting and cutting, was not used as we use an axe to-day, but the

Fig. 47.—Native using modern Adze.

handle was merely a means of holding it in position, whilst the back of the blade was struck with a stone or other article. This is clearly borne out both by the form of the axe and by the fact that many of the blades

are badly burred over at the back, where they had been struck with some instrument.

It may be remarked that all bronze and copper tools (not models) are much burred at the hammered ends, but very few at the cutting ends. This tends to show that they must have been used against softer materials than that of the tools themselves, because it is improbable that almost all our specimens of antique tools would have been abandoned or lost by the ancients in a freshly ground state. The author has seen very few tools of copper or bronze with edges showing signs of wear sufficient in extent to show that they were used against hard stone.

Fig. 48.—Axe.

A gradual development of the shape of the axe head took place as the art of metal working advanced, and finally blades with a socket for the handle came in, as shown in Fig. 49.

It has usually been said that the ancient Egyptians did not use handled hammers prior to Greek times. It is somewhat amazing that the sculptors, goldsmiths, and metal workers contrived to execute the best examples of their craftsmanship with no other hammers than hard stones held in the palm of the hand. The working of a piece of red-hot iron for instance in such a manner would seem to us to be at once a very difficult and uncomfortable operation.

The evidence is almost purely negative: there are no

contemporary illustrations of handled hammers in use, nor have specimens been found. On the other hand, there are one or two reliefs showing workmen smiting an object with a stone or similar object held in their hands.

To the non-archæological mind, it is also extraordinary that the fact that handles were used on battle axes from the most primitive times did not lead to their application to hammers.

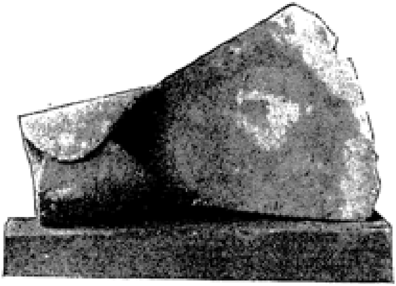

Fig. 40.—Socketed Axe Head.

Again, stone masons' mallets were used of precisely the same type as those of the present day, and specimens of the XVIIIth and XIXth Dynasties have been recovered. The use of handles to these would be thought to have found its necessary and obvious application to hammers of stone and metal.

There is no doubt that flint chisels were in use along with copper and bronze ones throughout the dynastic period. The similarity in type between some of these

old stone-cutting chisels and those of the present day is remarkable.

Chisels were required for several purposes. They were needed for wood-cutting, for stone-working, and for metal-working, the first two being the chief uses. A chisel for wood requires a blade with a longer taper to its cutting edge, and as a consequence the latter is sharper. Our wood chisels usually have wooden handles, as likewise have many of the ancient Egyptian ones. The latter must have been used more in the sense of wood-carving, because their form is such that blows with a hammer would merely have caused the blade to split the handle. Also, none of the specimens of such chisels in our museums shows any trace of having been hammered.

A chisel for stone-cutting must not have too thin a blade, but should taper off from the stem for a short distance only, and in this way the cutting edge is amply supported, by the body of metal behind, against the hard blows necessary in chiselling the stone.

Chiselling was largely supplemented by knife work. Cutting-out knives developed from a simple form in prehistoric times to that shown in Fig. 50 about the date of the xviiith Dynasty and later. Two cutting edges are clearly seen. These were doubtless used for the cutting out of wood, leather, and similar materials.

Amongst the first means used by the ancient Egyptians for securing the different parts of their structures in wood work, are the copper ties described in Chapter II. These copper strips were no doubt a development of leather ties which were used for so many similar purposes in the first stages of Egyptian civilisation. Another form is that of the clamp which was employed for fastening the planks of a roof to the rafter, or for similarly joining up the parts of a sarcophagus lid.

Nails of copper and bronze seem to have followed later, probably being derived from the rivets used for metal joints from the most primitive times, and specimens of all sizes have been found. Iron nails came in eventually, and examples are said to have been discovered belonging to the xth Dynasty. It was not until Græco-Roman times, however, that they began to be used at all extensively.

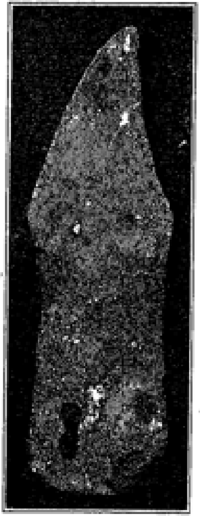

Fig. 50.—Cutting-out Knife.

The student will be impressed by the antiquated origin of many of our own tools and implements in every-day use. For instance, the ladder was used in the xviiith Dynasty. We find it illustrated on a bas-relief showing its use in connection with the siege of an ancient city. Weighing scales appear to have been conceived during the early part of the dynastic period soon after the working of metals was understood. There are many illustrations of them in the decorations of tombs, some of them, it may be said, not showing too close an acquaintance by the artist with the principles of the fulcrum and the lever. Other articles, indispensable to us to-day for their individual purposes, which were just as well known to the Egyptian artificers, are the plumb line, bellows, blowpipe, and scissors, the latter probably of comparatively late periods, and a development of the cutting-out knife.

The well-formed rivet heads in the photograph (Fig. 51) might almost pass as modern productions. They occur on a bronze door hinge, and show that our present type of headed rivets is very ancient.

Riveting of copper and bronze articles was necessarily a favourite means of jointing with the earliest Egyptians, because welding and brazing of these metals were

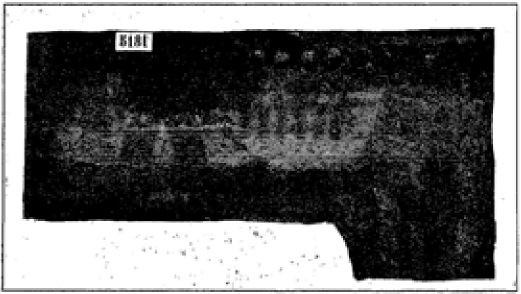

Fig. 51.—Rivet Heads on Bronze Door Hinge.

unknown to them. Even from prehistoric times we find the thin gold coverings fastened as handles to flint knives by means of gold rivets, but the idea of finishing off the ends in a properly shaped head does not seem to have come in until the influence of the Greeks made itself felt.

CHAPTER V.

THE METALLOGRAPHY OF ANTIQUE METALS.

The application of a special branch of metallurgical science, that of metallography, to antique metals is of recent date; but it provides much useful information on the stability of different physical forms of metals and alloys, and upon the corrosion of these substances.

Much that follows in this chapter must necessarily chiefly interest the metallurgist, but an attempt will be made to treat the subject in a plain manner, so that students of both metal-working and archæology may follow it readily, and the expert will be at liberty to pass over the explanatory paragraphs, and, if he does not agree with all the author's deductions, will doubtless draw his own conclusions from the data and the microscopical evidence which will be set forth.

Metallography is the science that treats of the internal structure of metals, and one of the chief means of investigation employed is microscopical examination. By viewing a prepared section of a metal or alloy through a microscope much useful information may be obtained as to its physical state, and even sometimes as to its chemical composition.

Antique metals, being generally very fragile, care and patience are necessary when cutting, sawing, and filing them in order to obtain pieces for examination. The

hack saw blades should be very thin ones, with fine teeth, and plenty of time should be given to the cutting.

The specimen for examination is prepared by filing a perfectly flat section, then rubbing the surface on two or three grades of emery paper, commencing with the coarsest, and subsequently polishing on a cloth wetted with water carrying an impalpable polishing powder in suspension stretched upon a board. It is essential that the emery paper be laid on a perfectly flat surface, and for this nothing suits better than a piece of plate glass. After washing, the prepared surface is etched by a reagent which will gently attack the metallic surface and bring into view, by selective corrosion, the different phases of which the microstructure is composed. The specimen is afterwards finally washed and dried, and is then ready for examination.

Metal sections cannot be viewed by transmitted light, as are substances usually submitted to microscopic examination, therefore some means of illuminating the surface, when moderate or high powers are used, has to be devised. This is generally done by fixing to the tube of the microscope, before putting on the objective, a fitting carrying a prism and having a radial hole, through which a strong beam of light, concentrated by a bull's eye condenser, is passed at right angles to the tube. The illuminant is either an electric light or a gas or petrol mantle lamp, but an ordinary microscope oil lamp will be found to serve quite well for visual, though not for photographic work.

A short description of the internal crystalline arrangement of metals is necessary. The microstructure of, *e.g.*, cast silver, if pure or almost pure, is made up, like that of all other metals, of crystal grains, which may be called "primitive" or primary, because they are

the original ones formed in solidifying from the molten state. The crystal grains have no regular external geometric form, although they are built up of ultra-microscopic crystals that do possess such form. The etching agent merely tints the surface in a uniform manner and brings into view the crystal boundaries. Fig. 52 shows the appearance of the crystal grains on a section of modern cast silver. Each crystal grain is a separate entity, and is made up by gradual growth along

Fig. 52.—Microstructure of Cast Silver.

multitudinous branches (called crystallites) from a centre, all spaces between the first branches being filled up by new branches, which continue to shoot out in all directions until the whole grain is solid. The shape of each grain is determined by the interference that the main or primary crystallites receive from those of neighbouring grains. Fig. 53 shows the branched form that crystallites follow. It is the structure of a silver-copper alloy. Copper, with which metal we are chiefly concerned in this work,

also shows irregular crystal grains when the polished surface is etched.

From the point of view of the metallographer, it is fortunate that the copper of the ancient Egyptians was impure. Analyses show that the principal impurities are arsenic, iron, lead, and bismuth. The fact that it generally contains appreciable amounts of iron and arsenic, separately or together, is of much use in investigations.

In an alloy of copper and arsenic, the latter metal,

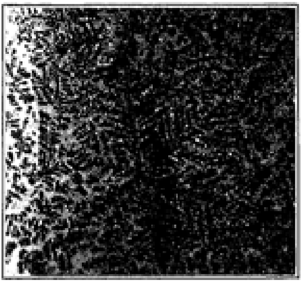

Fig. 53.—Microstructure of Silver-Copper Alloy.

up to a certain limit (about 4 per cent.), is held in a perfect state of solution even after solidification is complete, because it cannot be separately recognised microscopically, nor can it be separated by mechanical means from the copper. Such a mixture of two metals is called a solid solution, and in solidifying from the molten state the first portions of each crystal grain to crystallise—that is to say, the nuclei of the primary branches or crystallites—are richer in the metal with the higher

melting point (in this case copper) than the succeeding layers, and this gradual process goes on until the liquid metal of each portion solidifying last of all is rich in the metal with the lower melting point—viz., arsenic. This process is so gradual that there is no line of demarcation between the layers of different grades; they shade off into one another.

In the case of a mixture of copper and nickel, the first parts of the crystallites to solidify will be nickel-rich metal possessing the higher melting point. The explanation of the inequality of distribution of the second metal in such cases is due to the fact that diffusion is an extremely slow process as compared with crystallisation.

In specimens of such alloys, instead of the surfaces of the grains appearing uniform in tint under the microscope, each one has dark feathery markings due to the fact that the intensity of action of the etching medium varies with the proportion of the added metal at each spot. These markings are technically known as "cores," and the reader should note that this is a very different application of the term from that previously used in connection with making hollow castings in metal.

As may be expected, the shaded "core" markings usually follow the forms of the crystallites, and they gradually shade off towards the edge of the crystal grain. All metals that are to some extent soluble in copper when solid, produce such markings when a polished surface of the alloy is etched. The important metals possessing these properties (not all to the same extent) are, iron, arsenic, nickel, tin, and zinc. A photomicrograph of a modern copper-zinc alloy showing the shaded markings, and also the boundaries of the cast or "primitive" crystal grains, is given in Fig. 54. At

Fig. 54.—Microstructure of Cast Brass.

a higher magnification (Fig. 55) the graduated nature of the shaded markings is clearer.

As the shadings are caused by the etching reagent,

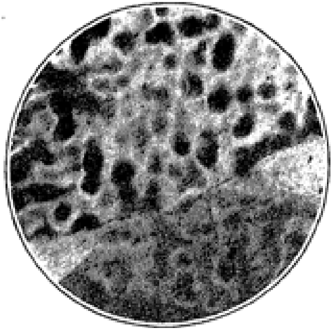

Fig. 55.—Microstructure of Cast Brass.

it will obviously depend upon which of the two metals in the alloy is more rapidly attacked by the reagent used whether the markings shade from light to dark or *vice versa*.

In some cases, however, the core markings, instead of graduating from light to dark, or *vice versa*, in plain brown or black, assume colours of different tints. This is especially the case when ammonia is used for etching.

An alloy in the physical state previously described cannot be called homogeneous. As we have seen, some parts hold more zinc, or arsenic, as the case may be, than others. It is, however, possible to make it homogeneous—that is, provided the alloy is made of such a mixture of the two metals that complete solid solubility occurs. Some metals are not soluble in copper in all proportions when solid.

Homogeneity can be brought about in the alloy by heating it (without melting) for a length of time, which varies according to the temperature applied. The arsenic, zinc, or other of the soluble metals mentioned, is thereby caused to diffuse into the copper until the substance of the whole is uniform and homogeneous, the etched section afterwards showing only a uniform tint from grain to grain. Such a solid solution is considered to be in a state of perfect equilibrium. The foregoing helps us to understand the term "solid solution," because the arsenic, etc., diffuses whilst the alloy is in a solid state, and afterwards remains uniformly distributed throughout the mass indistinguishable microscopically from the copper.

It will be obvious that if the cooling of the alloy, when first cast, were made sufficiently slow, it would have the same effect on the internal structure (by enabling diffusion to proceed completely), as the subsequent

heating of the solid alloy, but this is impossible because it is impracticable to maintain a sufficiently slow rate of cooling.

The useful alloys of gold with copper and those of gold with silver belong to the same category, as both copper and silver form solid solutions with gold, showing shaded markings on etched specimens produced by casting, which disappear on thorough annealing.

The size and form of the shadowy "core" markings in all the alloys described vary with the rate of cooling from the liquid state. If the cooling be slow, the crystal grains will assume large proportions, and the cored markings will be more spread out and much more shadowy in their graduation from dark to light upon the etched surface. If cooling is rapid, the grain will be small, and the shaded markings will be more distinct than in a specimen of the same constitution cooled more slowly and having larger crystal grains. The crystal grains in any metal or alloy may be so small that they require a high magnification to bring them into view, or they may be large enough to be macroscopic. It will be obvious that under working conditions cooling will always be more rapid in a small mass of metal than in a large one, the methods used being similar, and we may, therefore, say that, in general, crystal grains are larger in large castings than in small ones.

The reader will now understand that a polished section of cast copper containing as an impurity arsenic, iron, or similar element, soluble to some extent in the solid copper, will, when etched, consist of crystal grains with shadowy markings, and, when thoroughly annealed and repolished and etched, the shadowy markings will be found to have disappeared, the final structure being similar to that of a pure metal—*i.e.*, homogeneous—

nothing but lines denoting crystal boundaries being visible on the surface of the microsection.

The metallography of bronze is rather more complicated, because tin is only soluble in copper up to 16 per cent. in the solid state, and if the tin is in excess of that, a second constituent remains even after prolonged annealing. As a result of ordinary casting, bronzes containing more than 8 per cent. of tin show the presence of the second constituent, and between 8 and 16 per cent., it is only as a result of annealing that homogeneous solid solutions can be obtained. Up to a tin content of about 8 per cent. the previous remarks concerning arsenic-copper alloys apply fully to bronzes, and samples of the latter containing more than that percentage of tin are not of importance to us in this work, as the alloys are only found in antique bronze statuettes and other articles not intended for useful purposes.

Copper and silver alloys are complicated in a rather different manner, consequent upon the fact that copper and silver are not mutually soluble in the solid state in all proportions. On the one hand, copper can only retain a small percentage (about 6 per cent.) of silver in solid solution, and silver can only retain 5 per cent. of copper in solid solution.

Any mixture of these two metals between the limits of these two solid solutions consists, therefore, of primary crystallites of either the copper-rich solid solution, if copper is in excess, or of silver-rich crystallites if silver is in excess. In each case the crystallites are embedded in a matrix which has the same constitution. It is known as an eutectic, and is composed of a mechanical mixture of the two solid solutions, appearing on the etched section as fine alternating layers. The matrix is, therefore, heterogeneous: its composition is constant, and the

temperature at which it solidifies, which is lower than that of the crystallites, is also constant. Therefore, as this matrix solidifies round the primary crystallites throughout the mass, there are no crystal boundaries to be seen in an etched section, but the crystal boundaries may be distinguished by the different orientations of the eutectics. The alternating layers of the matrix, or eutectic, can readily be distinguished on the prepared surface by using moderately high magnifications.

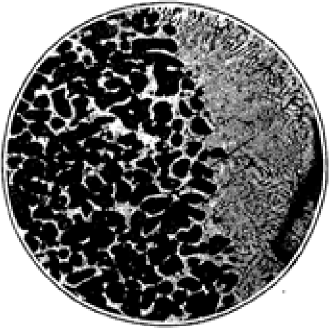

Fig. 56.—Microstructure of Silver-Copper Alloy showing Eutectic. × 90 d.

In each of the two cases, the quantity of matrix will vary with the composition, because the mutual solubilities are constant. The copper-silver matrix (eutectic) may be seen in Fig. 56, at the side adjacent to the dark coppery crystallites. The two phases comprising the matrix are clearly visible. This photomicrograph is of a Greek coin, and is taken at a magnification of 90 diameters. Silver containing a small amount of copper

or copper containing a little silver—that is to say, less than the limit of solubility of the added metal in each case—will show crystal grains on the polished surface, because of the absence of eutectic. There may be "cores" in such an alloy, but, as the quantity of the metal in solution is small, they may not be very distinct.

The parts of the structure of copper-silver alloys that are rich in copper are more deeply attacked by the etching reagent than the silver-rich parts, assuming a dark red, brown, or black colour, whilst the silver-rich parts remain yellow-white. The copper-rich crystallites will never appear with silver-rich crystallites on the same specimen, and if either metal is present in amount above that soluble in the other, it will be found associated with eutectic.

Lead and bismuth form alloys with copper of a different class. They are practically insoluble in both copper and bronze in the solid state, and, therefore, during solidification they are rejected by the solidifying metal, and are thrown out to the boundaries, where they remain liquid until the temperature cools down to the freezing point of lead or bismuth, as the case may be, when they crystallise in the form of isolated globules if the quantity is very small, or as a more or less continuous network enveloping the crystal grains of copper (or bronze), if they (the lead or bismuth) are present in sufficient quantity. Lead in copper or bronze is detected microscopically on the unetched surface as black globules or streaks, but if the specimen is a much corroded one, they may be grey in places owing to corrosion. Patches of cuprous oxide (due to corrosion), which are a light blue colour, may at first be mistaken for lead globules.

Copper, ancient and modern, generally contains another impurity, cuprous oxide, which has to be taken into

consideration. It occurs in practically all copper to some extent, and forms with the latter a series of true alloys of the eutectiferous variety. The oxide is insoluble in the solid copper and forms with it a recognised eutectic mixture of constant composition containing 3·5 per cent. of cuprous oxide, solidifying at a temperature, 1,063° C., lower than that of either of the two constituents just as happens in the case of mixtures of copper and silver. A piece of copper containing a percentage of cuprous oxide less than the eutectic proportion (which is necessarily the case in copper for useful purposes, as much oxide renders the metal unworkable) consists of grains of copper with patches of eutectic. This eutectic has a characteristic structure, and is readily observed in a polished section without etching.

In the previous pages we have dealt only with metals and alloys in a freshly cast condition. We may now proceed to consider what happens to the internal arrangements of such metals and alloys when they are submitted to deformation by hammering or other work of a similar nature applied to them in the cold state, in order to form them into some kind of a vessel or tool.

We can readily imagine what would take place inside an orange if it were crushed. The different sections would be quite unrecognisable, and the bounding surfaces would be crushed into and through one another. Hammering a metal has a similar effect upon the crystal grains, tending to elongate them in the directions at right angles to the applied force: their boundaries are rendered indistinct, and any globules of lead or other insoluble impurity such as cuprous oxide are flattened and lengthened out. In unannealed solid solutions the shaded "core" markings are also flattened and lengthened. In a specimen severely hammered these core

markings and even the granular boundaries will be so flattened, extended, and confused, as to be unresolvable by the microscope. The etching of such a specimen and the detection of the nature of its microstructure, if its history is unknown, is a matter of some difficulty. Fig. 57 shows the structure of worked modern brass.

A cold hammered metal usually also shows many

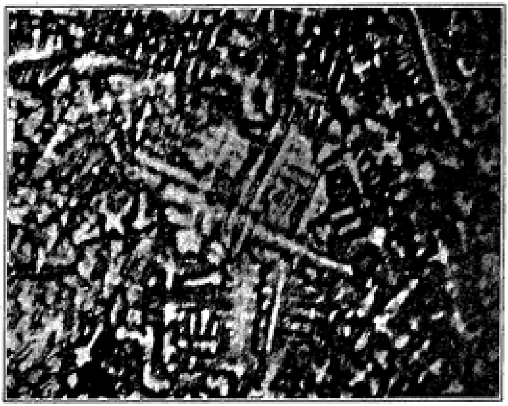

Fig. 57.—Microstructure of Modern Worked Brass.

lines, known as slip-bands, traversing the crystal grains, sensibly parallel in form: they are produced by the slipping of the different parts of the grain over one another, and may proceed across the surface of a grain in more than one direction. They are revealed by etching (Fig. 58). A hammered alloy having "cores" does not, as a rule, show slip-bands very distinctly, because

the shaded markings tend to mask them, and in an alloy consisting of two constituents, one harder than the other, they may not occur at all. They are seen best in specimens of worked bronze or brass that have been thoroughly annealed before the work. When sufficiently cold-worked to cause a confused structure, then no slip-bands will be visible.

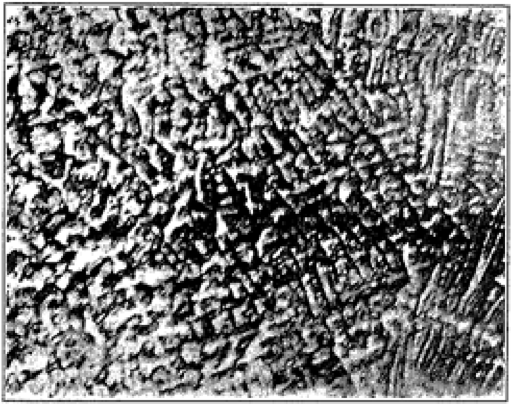

Fig. 58.—Microstructure of Twisted Brass showing Slip-bands.

It has been mentioned in a previous chapter that the working of most metals and alloys in the cold state hardens them to such an extent as to render further manipulation impossible without cracking. It is, therefore, necessary to anneal them in order to bring the metal back to its original state of softness. Annealing is the process of heating a metal or alloy for a certain length

of time to a temperature below its melting point, in order to soften it, or to render it perfectly homogeneous. If the temperature is a high one, approaching the melting point, the time need only be short, but the time becomes longer as the temperature is lowered. The rate of cooling after annealing is not material.

In the forming or "raising" of a vessel from a sheet of metal several annealings are required; in fact, the number of annealings depends upon the amount of "work" to be done.

We have noticed that annealing of alloys causes equilibrium to be attained by diffusion of soluble metals, but in worked specimens of metals or alloys in the form of solid solutions it also brings about another change. A recrystallisation occurs, in spite of the fact that fusion has not taken place. The whole mass rearranges itself internally, and a crystalline system quite different from the original cast one is formed. The boundaries of the latter are very irregular and jagged, and the grains exhibit much interpenetration, besides an obvious elongation in the direction at right angles to the cooling surfaces. In a solid solution "cores" would also be present. The boundaries of the new or "secondary" grains, that are induced by the "work" and the subsequent annealing, are, on the contrary, much more regular in shape: the boundaries take the form of straight lines, and the grains themselves are much more regular and are very angular. A photomicrograph of hammered, annealed brass (copper 70 per cent., zinc 30 per cent.) is given in Fig. 59. There is also another peculiarity which distinguishes secondary grains; it is known as twinning. We need not enter into a full explanation of this characteristic, but it will suffice to say that it is primarily due to the original interpenetration of the cast or primi-

tive grains and to pieces of one grain being separated and embedded in another by the "work." These broken fragments are compelled to crystallise with the grain in which they are embedded in an arrangement different from their own, and they take the form, on the etched surface, of parallel bands extending wholly or partly across the surface of the grains. These parallel twin

Fig. 59.—Worked Brass annealed at 600° for half an hour.

markings may occur in cast metals, being due to internal stresses brought about by unequal contraction during solidification, but in such cases they are present in very small numbers.

The secondary type of crystal grains with twin markings have been found to occur in copper produced by electrolytic processes, and the author has also found it in

fragments of precipitated copper from the surface of a bronze mirror, an interesting subject, which will be dealt with later, but these occurrences are of minor importance, and do not affect the question we are now about to consider—viz., the uses of microscopic investigations of structure for the detection of methods of manufacture of antique metal objects.

The secondary grains possess a property peculiar to themselves. With continued heating or a raising of the temperature, they grow in size, there being no limit, except that of the mass itself, to the dimensions that a grain may attain, but they preserve their straight boundaries and angular forms. The primitive grains in a cast metal or alloy do not possess this characteristic, except in a very small degree, caused, no doubt, by stresses existing within the mass, owing to differences in the rate of cooling of different parts. A point of some interest is that this property of growth which the crystal grains of a worked metal possess, is permanent: it does not lapse. The author has proved by experiment that the grains in such a sample will continue their growth if annealed in spite of the fact that the growth was first initiated perhaps five or seven thousand years ago. A worked metal is in a strained condition: these strains are relieved by the application of heat, and the result is the new structure of secondary crystal grains. It would not be unreasonable to suppose that ageing alone might relieve these strains, but from specimens examined it is possible to say that after more than 2,000 years, the internal strains still exist, as is demonstrated by the fact that recrystallisation and crystal growth ensues when the antique metal is annealed.

A photomicrograph of the same sample of brass as that of Fig. 59 is given in Fig. 60, which was taken after

further annealing at a temperature approaching the melting point.

Globules of lead or cuprous oxide contained in alloys flattened by hammering are caused to resume a globular form by annealing, if the temperature is sufficiently high.

As was explained in the case of cast alloys, all "core" markings disappear during the annealing, because the

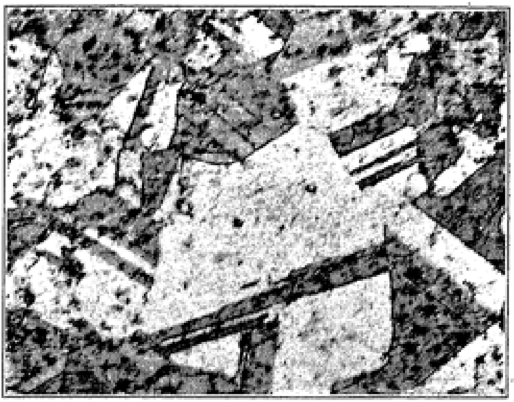

Fig. 60.—Microstructure of Annealed Brass after further annealing to 800° for half an hour.

metals present as impurities or constituents (to which the "cores" are due), diffuse uniformly through the mass.

If such an alloy is heated and hammered while hot, the recrystallisation proceeds simultaneously and the effects are similar, though the "core" markings will

not, as a rule, be entirely eliminated unless the heating is sufficiently prolonged.

With alloys having a microstructure comprising crystallites in a matrix of some kind, as, for instance, those of copper and silver, the case is somewhat different. Hammering or other cold working causes a breaking up, flattening, and distortion of the different structural phases, as explained with respect to pure metals and solid solutions, but the subsequent annealing, although the process of crystalline re-adjustment that ensues must be analagous, does not bring about similar visible effects in the microstructure. After the annealing, the crystallites do not reappear on the etched surface in their original branched form, but as rounded, isolated masses surrounded by the eutectic matrix, the two components of which are much more rounded and indistinct than they were in the original cast state, provided, of course, that the temperature of annealing is not higher than the melting point of the eutectic, which would produce incipient fusion.

Crystallites are essentially indications of solidification from the liquid state; if once distorted or broken up by "work," they can never be made to reappear by annealing. Fusion alone would produce fresh ones.

The reader will have gathered from what precedes, that it is generally possible to ascertain, from the microstructure of specimens of alloys here dealt with, the original method of manufacture. Some may have been cast; others may have been hammered from a disc of metal. In any antique object of metal or alloy made by simple casting there will usually be crystallites in the microstructure: annealing cannot destroy them, although by causing diffusion it may remove the evidence for their presence by the disappearance of the core markings.

A cast metal composed of grains, not having "core" markings, will show irregular grains possessing jagged and interpenetrating boundaries, and the trained eye readily distinguishes them from grains of the "secondary" type.

A cast specimen afterwards hammered to shape when cold, without any annealing, will show a confused structure flattened and distorted, any cores present being crushed and lengthened. A similar specimen annealed subsequently to the working will possess quite a different "secondary" type of structure, as previously explained.

There now remains to be considered the microstructure of a metal or solid solution, say a bronze containing 5 per cent. of tin, which has been worked and annealed several times, but left finally in the state produced by hammering the annealed structure. The regular angular crystal grains produced by annealing, when hammered are flattened and distorted, as are cast grains: they also show flow lines traversing each grain that has suffered distortion (see Fig. 58).

The work of the author has shown that all the structural characteristics of cast, worked, or annealed specimens previously worked or not, as already described, are permanent ones—that is to say, they are just as visible to-day in antique specimens as they were when freshly prepared thousands of years ago.

The usual method of etching specimens for microscopic analysis is by immersion in a reagent having a slightly corrosive action on the surface, such as dilute acid, dilute ammonia, etc. Etching of modern specimens is not difficult, requiring only a certain amount of practice in judging when the attack has gone far enough and promptly stopping further action by washing. If the etching be carried too far, there is no alternative to

repolishing and etching again. Antique metals containing copper, however, are often rather more difficult to etch, and require much closer watching during the immersion. This is chiefly due to the fact that they invariably contain oxides and salts of the metal either on their outward uncleaned surfaces or penetrating into the metal itself. These oxides and salts are much more readily acted upon by the etching medium: they quickly go into solution, and as a consequence the polished metallic surface may re-precipitate the copper from the solution, so that it forms a skin on the surface. These difficulties are best overcome by removing as much as possible of the oxidised crust from the surfaces of the specimen not required to be etched, or by covering them with a layer of wax. After that the etching should be carefully watched and the surface constantly examined: the time required is often not longer than one minute. As a rule, the reagents should be more diluted than those used for ordinary use with modern alloys.

It is as well during etching occasionally to move the specimen about in the liquid to remove any bubbles of gas that may have formed on the surface, thus hindering the attack. After the final washing, drying should be carried out as quickly as possible. This is more necessary with antique metals than modern ones, as the crevices in the former are likely to hold salts which may be brought to the surface by prolonged action of moisture. In most cases a soft napless rag may be lightly wiped over the polished face, or the specimen may be rinsed in ether.

A good way of viewing "cores" in solid solutions is to throw the microscope objective slightly out of focus, when the parts of the structure standing in relief are emphasised, because in some instances the etching medium

may not produce "core" markings sufficiently dark in tint to be clearly visible except to the expert.

Another method of developing the structure on micro sections is the heat-tinting process. This consists of gradually heating the specimen in air until slight oxidation films form on the surface, but with antique metals it gives very poor results.

The beginner is advised to make a point of repeating the polishing, etching, and examination of a specimen, because occasionally freak markings occur on the surface due to unequal action of the etching reagent, to the crystallisation of salts (imperfectly removed by the washing), or to the deposition of films of metallic copper upon the bright surface.

The prepared surface should be perfectly clean and free from grease. It is useful to rinse in benzene or ether before submerging in the etching fluid.

The following reagents are most suitable for the different kinds of antique metals and alloys :—

Copper and Bronze.	Ammonia.
	Ammonium persulphate.
	Dilute nitric acid.
Gold.	Aqua regia.
Silver and Electrum.	Nitric acid.
Iron.	Picric acid.
	Dilute nitric acid.

After a little practice the preparation of a metal section for microscopic examination becomes an easy matter. The chief points are :—

1. The polished surface must be quite flat, especially if high powers are to be used.

2. Scratches made by the file must be removed by emery paper, each grade of which is applied in a direction

at right angles to the previous one, so that it is easy to see that marks made by the previous paper are removed.

3. Washing to remove all grit between each stage of the grinding and polishing.

4. Careful watching during etching to prevent it going too far. Directly the surface shows signs of losing its metallic brightness, it should be removed and examined.

For further details of preparation of specimens, the reader should refer to the books devoted to the microscopical study of metals. For polishing, the author has used a Swiss nail powder known under the name of "Diamantine" with satisfactory results. This is not the expensive white powder of the same name usually employed by metallographers. The finest jeweller's rouge also gives good results. All fine emery papers and polishing cloths should be quite free from gritty particles. Selvyt cloth suits admirably for polishing. A microscopic examination of the polished surface should always be made before it is etched, as much useful information can often be obtained in this way. Variations in hardness of the different phases comprising the microstructure cause some to be more worn away by the polishing than others that are harder, and thus the latter stand out on the polished surface in slight relief. Again, certain structural characteristics can best be observed before etching, such, for instance, as lead in copper or bronze, appearing dark against the body of the salmon-coloured or yellow surrounding metal; and cuprous oxide in copper, the former appearing blue against the salmon-coloured copper. In some cases the boundaries of the crystal grains, and in others flow lines due to hammering, more especially in antique specimens, may be clearly observed. Further, it may be said that etching would

in some instances tend to mask these effects by the production of others of more noticeable character.

As the copper articles of the earliest Egyptian periods contain impurities, they must be regarded as alloys. For instance, in the analysis of the copper strip (p. 68) we find that the chief impurity is arsenic, and, therefore, we may regard the metal as an alloy of copper and arsenic. The other impurities which are present in much smaller amounts, do not disturb the general arrangement of the microstructure. The following is a list of the antique alloys with which we have to deal :—

Copper with a little arsenic as main impurity, generally also with iron.
Copper with tin less than 8 per cent. (bronze).
Copper with tin between 8 and 16 per cent. (bronze).
Copper with zinc less than 30 per cent. (brass).
Gold with silver.
Gold with copper.

All the foregoing alloys, in the mixtures that are of practical importance and of which antique specimens exist, form solid solutions.

Copper and silver together form solid solutions, but they also form an eutectic mixture. Lead forms no solid solutions with metals that come under our consideration.

It has already been stated that the structural and physical effects of a long annealing at a low temperature are similar to those produced by a higher temperature applied for a shorter time : this rule has been considered so true by many metallurgists that it has been considered that annealing effects could be brought about in a metal even at atmospheric temperatures, provided a sufficiently long period of time were allowed. The author's investigations upon antique Egyptian metals have shown,

10

however, that if such a process does take place it is infinitely slow, and is quite imperceptible after about 5,000 years. For all practical purposes it may be said that a more or less elevated temperature is required to produce the structural alterations due to annealing—viz., diffusion in a heterogeneous solid solution—and recrystallisation and crystal growth in a worked metal or alloy.

An antique specimen demonstrating the truth of this is a copper dagger which is over 5,000 years old, having been made during the 1st Dynasty. It has been authoritatively assigned to this period by the Egyptian archæological authorities, and is considered by the author to have been originally contained in a sheath of the same metal, but the latter, being very thin, had entirely oxidised before it was discovered.

The following is the analysis of the metal, omitting oxygen :—

Arsenic, ...	·39 per cent.
Lead, ...	trace
Iron, ...	·08
Bismuth, tin, and nickel, .	nil
Copper (by difference), . .	99·53

The comparative purity of the metal is worthy of remark, particularly injurious impurities, such as lead and bismuth, being entirely absent. A similar absence of these impurities has been observed by the author in most other antique copper implements intended for mechanical purposes.

The dagger had apparently been made by first casting the metal roughly to shape, and then finishing by hammering when cold, but as some parts of the section near the edges showed a little twinning, perhaps a slight

amount of hot work had also been done on the object. That it had never been systematically annealed, and that no appreciable diffusion had occurred during its lifetime was abundantly clear. On etching the section, the original core markings came out with distinctness, as shown in Fig. 61.

Close examination of the etched section showed that recrystallisation had taken place in a somewhat peculiar manner; there were indications that the actual recrystallisation had only affected one part of the structure —the arsenic-rich areas—which had taken the form of attenuated crystal grains following the meanders of this particular phase, thus leaving the other parts (copper-rich) in the form of islands of varying sizes. This can be seen at a higher magnification in Fig. 62.

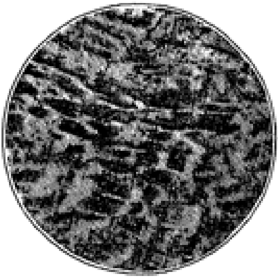

Fig. 61.—Microstructure of Copper Dagger showing Cores.

It may be pointed out that the metal of the dagger in its original cast state would not show these clear crystal boundaries. There is a possibility, however, that they were induced by the very slight amount of hot work which appears to have been done on the dagger. The author, however, rejects this idea, because, near the edges of the specimen, as stated, the crystal grains bear no resemblance to the type produced on such alloys by hot work or by annealing cold-worked samples, but are more like the primitive "cast" type of grain. Moreover, hot work or annealing would have produced

recrystallisation in the copper-rich islands. He prefers not to venture any opinion as to whether the recrystallisation was brought about in relief of the internal stresses set up by the cold hammering, or whether it was induced either by the highly crystalline properties of arsenic or by the presence of the cuprous oxide globules.

Annealing the metal produced the results that would be expected in a modern sample of worked copper of the same composition, as shown in Fig. 63. The grains assumed a regular form, the oxide migrated to the granular boundaries, and the "cores" disappeared.

Fig. 62.—Microstructure of Copper Dagger showing Cores.

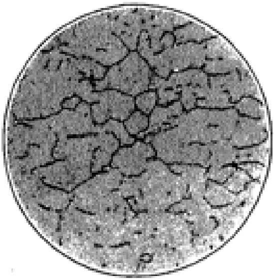

Fig. 63.—Copper Dagger after annealing.

This micrograph was produced by etching with chromic acid, and afterwards slightly polishing; but, of course, before the latter was done, it was well observed that "cores" were absent. The polishing has obliterated the boundaries here and there.

Another old sample which clearly demonstrates the persistence of the cast "cored" structure in copper is the strip of the XIIth Dynasty described in Chapter II. (p. 65).

This strip was hammered to shape from a cast rod whilst hot, which was the ancient Egyptian's method of preventing cracking whilst working the metal, and at the same time ensuring softness. The heating was not, however, prolonged, and cannot be considered as annealing. This is apparent from the photomicrograph (Fig. 64), which clearly shows the large cores, due to arsenic, flattened out as they were by the hammering. That the metal was worked hot is shown by the slight amount of fine recrystallisation which may be detected

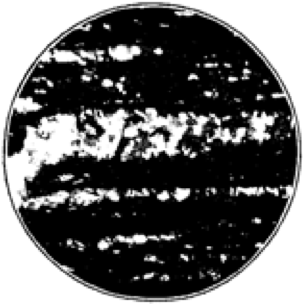

Fig. 64.—Microstructure of Copper Strip. XIIth Dynasty.

Fig. 65.—Copper Strip (Fig. 64) annealed. × 90 diam.

in the light parts of the structure. In order to show how annealing would have removed these cores, the author heated a sample, and Fig. 65 shows the subsequent structure. The recrystallisation is now apparent over the whole surface, and the "dark" cores have been dissipated. The long streaks traversing the photograph are strings of cuprous oxide.

In the case of the copper razor (Fig. 29), it is

interesting to note that probably some hot work was done on the metal, because there is some secondary crystallisation in places. Fig. 66 shows the original structure, and Fig. 67 the structure after annealing by the author.

Fig. 66.—Microstructure of Copper Razor (Fig. 29).

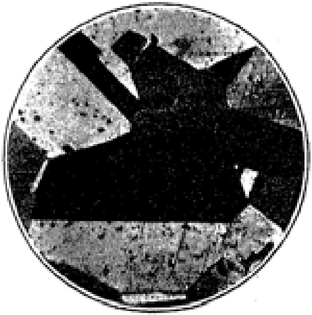

Fig. 67.—Microstructure of Copper Razor (Figs. 29 and 66) annealed.

The copper knife illustrated in Fig. 68 also showed pronounced core marking (Fig. 69), and when a piece of the metal was annealed the cores disappeared and crystal growth set in (Fig. 70).

Fig. 68.—Copper Knife.

The next three photomicrographs are from an adze or axe blade, described in the previous chapter (Fig. 48). Fig. 71 shows the original cored structure; Fig. 72 shows

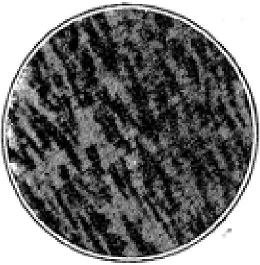

Fig. 69.—Microstructure of Copper Knife. × 75 diam.

Fig. 70.—Copper Knife (Fig. 69) after annealing. × 75 diam.

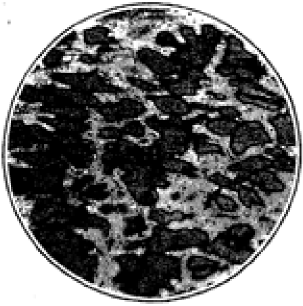

Fig. 71.—Microstructure of Axe-head (Fig. 48).

Fig. 72.—Microstructure of Axe-head near Cutting Edge.

how the cores were flattened out near the cutting edge which had been hammered out cold, whilst Fig. 73 shows the homogeneous secondary microstructure which was produced by annealing in the author's laboratory.

As a specimen of cores in an antique bronze, the photograph given in Fig. 74 is included. This is taken from a section of metal from the Roman or Byzantine pot shown in Fig. 30, and described in Chapter II. The photograph shows cores and spots of lead, and the shape of these prove that no work has been done on the metal.

Fig. 73.—Same as Fig. 72, after annealing.

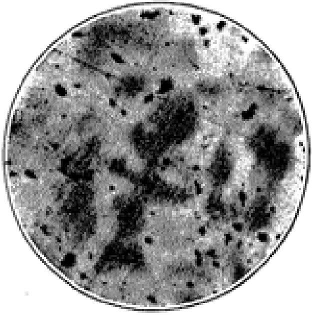

Fig. 74.—Microstructure showing Cores and Lead Spots in Bronze Pot (Fig. 30).

Cores in the metal of a gold ring are shown in Fig. 75. The author's experience is that in almost every sample of antique copper and many bronzes " cores " are present, and this, besides showing that systematic annealing had not been applied, also demonstrates the permanence of the cast " cored " type of microstructure. If any diffusion has taken place during the long period of time that has elapsed since the articles were made it is not apparent.

Doubt may be expressed in some quarters that the dark striations in some of the photomicrographs are really "core" markings. That they are is amply indicated by the fact that they invariably disappear after annealing, that they are always flattened in a direction parallel to the hammered sides, and that they follow more or less the undulations of the surface.

It is possible to say that many of the articles were specially cast roughly to shape and not made by shaping

Fig. 75.—Microstructure of Gold Ring showing Core Structure.

a piece of metal cut from a large mass. This is deduced from the fact that the cores are proportionate in size to the section of the article—that is to say, speaking generally, in a large mass of metal the cores would be large in area, and thus if a small piece were cut off to make a certain object, it could be detected by the cores being out of proportion to the mass of the object itself. The rule cannot be considered an absolute one, but, seeing that the methods of manufacture would be general

ones, it is useful as a guide when endeavouring to ascertain by investigation of the microstructure how any particular article was made.

It may be added that the "cores" in an etched specimen of unannealed hammered alloy become more conspicuous and more defined, as a rule, than they were when the metal was in its previous cast state, because by flattening and compressing them they are rendered denser and the shading off towards the edges is thus made less gradual.

The permanence of the crushing effects of cold work done upon a metal or metallic solid solution possessing the recrystallised microstructure induced by an annealing after previous "work" has also been proved.

A small rod of brass (Roman), which had been twisted on its own axis when cold, showed this feature very well. In this case the distortion of the crystal grains was caused by twisting instead of hammering, but the effects upon the microstructure caused by the two processes were similar.

Fig. 76 is a photomicrograph of a section of this rod taken near the edge at a magnification of 90 diameters. Many of the grains will be seen to be marked with parallel flow lines caused by the slipping of different parts of a grain over others in order that the grain might accommodate itself to the new form imposed upon it by the work. The darker patches are due to corrosion. The specimen is about 2,000 years old, and, therefore, the strained type of microstructure appears to be quite permanent. A piece of gilt copper strip of earlier date also demonstrates this, as shown in the photomicrograph given in Fig. 77, taken at a magnification of 100 diameters. Lamellæ due to hammering after annealing are clearly seen.

Because annealing, as a process of manufacture, was not applied, so far as investigations teach us, prior to Roman times, there are no specimens that would demonstrate the permanency of the distorted, or, to borrow a mineralogical term, the "cataclystic" structure, of greater age than about 2,000 years, but there is no doubt that if such specimens of metals first annealed and then worked cold do come to hand, they will show that this type of microstructure is as permanent at atmospheric temperatures as the "cored" structure previously dealt with.

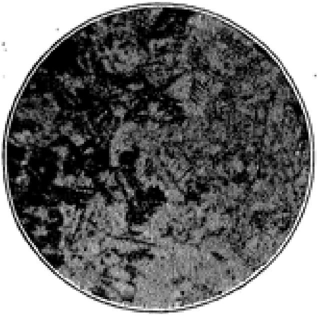

Fig. 76.—Microstructure of Twisted Brass. × 90 diam.

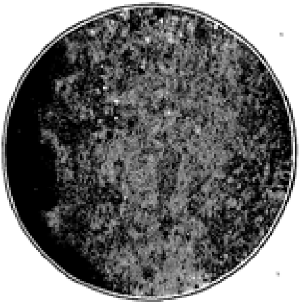

Fig. 77.—Microstructure of Gilt Copper Strip. × 100 diam.

In the structures of some of the early specimens of copper and bronze articles (as, for instance, the copper razor, Figs. 29 and 66), there is found a slight amount of recrystallisation due to a little hot work having been applied, and this enables us to assert that this effect of annealing upon the microstructure of metals and alloys has not been caused at atmospheric temperatures. In all the specimens examined, the new or secondary

crystal grains were of a fine order, being only visible under a moderately high magnification. It has been stated already that proper annealing of a worked metal or alloys causes growth of the new crystal grains, and that such growth is proportionate to the temperature used and the period for which it is applied. If, therefore, the structural changes of annealing took place at atmospheric temperatures, it would be reasonable to suppose that the enormous age of some of the antique examples would have been sufficient to promote crystal

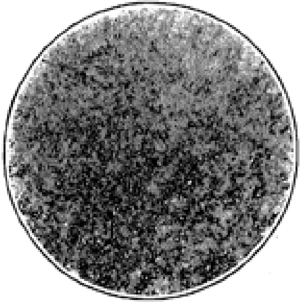

Fig. 78.—Rivet showing Fine Crystals. × 90 diam.

Fig. 79.—Microstructure of Silver Bead. × 90 diam.

growth until it became coarse. If any such growth does take place at normal temperatures, its rate must be infinitely slow, because the secondary crystal grains of a copper rivet, thousands of years old, are still so small to-day as to require a magnification of 90 diameters to resolve them, as shown in Fig. 78.

As an example of a different kind of alloy, silver-copper may be taken. The examination of silver beads, made

by the shaping of half-spheres over a suitable core, and then joining these halves together by a process similar to "wiping," shows that the structure is the same as it must have been at the time of its manufacture. The structure of such a bead at a magnification of 90 diameters is shown in Fig. 79. The small light-coloured islands of eutectic matrix are still elongated and flattened in a parallel formation in the direction at right angles to that in which the hammering was done. We can tell that annealing was not applied, because it would have caused the copper-rich parts to ball up and the matrix to appear on the microsection as more or less circular films around the dark masses. The period to which this bead can be assigned is doubtful, but it is probably of Roman origin.

The author has always found the original cast crystallites in antique specimens of cast silver-copper alloys *in situ*, surrounded by the well-known matrix, just as they were when formed during solidification, no structural changes having transpired during the lapse of time, as, for instance, in the case of the head of a statuette of the god Osiris, made of silver-copper alloy (see Fig. 80). The very dark portions in this photograph are due to corrosion, and will be dealt with later.

Whatever changes in microstructure take place as a result of ageing, it is clear that, in the cases of the alloys dealt with, these effects must be extremely small. It has been shown that diffusion in solid solutions, re-crystallisation, and crystal growth do not take place at atmospheric temperatures over periods reaching to five thousand years, at least not to such an extent as to be noticeable under the microscope.

It has already been explained that it is generally possible to say whether an article was produced by

raising or by simple casting, and it has been shown that raising of copper and bronze, being dependent upon annealing, was of comparatively late introduction, probably Roman. The bronze ladle described in Chapter II. (Fig. 31) may be taken as a support of this contention. The metallographical evidence that this vessel was made by casting is given in Fig. 81, which is a photomicrograph at a magnification of 100 diameters, showing that the original crystallites formed during solidification when cast, are still present.

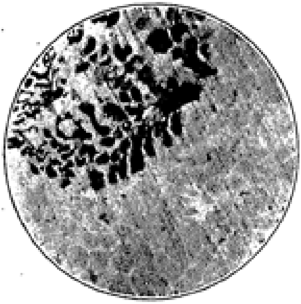

Fig. 80.—Microstructure of Silver-Copper Statuette.

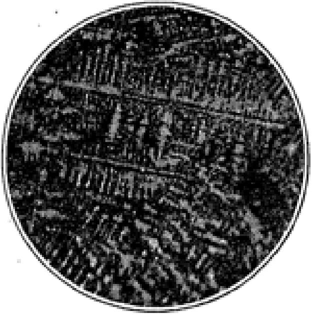

Fig. 81.—Microstructure of Bronze Ladle (Fig. 31). × 100 diam.

The two Roman vases described on pp. 49 and 69, although of an external form that could have been produced by raising, were actually cast. Another specimen showing the same feature is the Roman or Byzantine pot, shown in Fig. 30, with spout and handle, which also was cast in one piece. Fig. 74 shows the cast cored structure taken at the point where the handle joins the body. Further notes on this vessel will be

found on p. 173. The ornamentation of the spout, following the form of a lion's head, was, however, not done in the moulding, but was carved by a chisel or similar tool after casting. This is indicated by the photomicrograph (Fig. 82), which was taken from a longitudinal section of the spout. Traces of "cores" may be seen in the neighbouring cast crystal grains, whilst near the edge, which is that of the outer surface of the spout, flow lines caused by the chiselling are clearly

Fig. 82.—Microstructure of Ornamented Pot showing Flowlines.

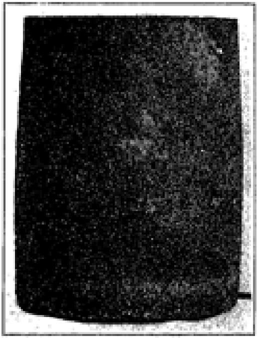

Fig. 83.—Roman Bronze Jar.

seen. The edges of the inner surface showed no such flow markings, because no work had been done on that surface.

Microscopic examinations have proved that even such simple articles as bronze mirrors, knives, arrow tips, chisels, and plain ring bracelets, were, until the period of the Roman occupation of Egypt, made by casting in moulds.

The Roman vessel (Fig. 83) bore strong traces in its microstructure of having been made by raising. Etching brought out secondary crystallisation of a fine type, and the form of the vessel itself rather tended to indicate "raising" as the method of manufacture. The presence of flow lines in the crystal grains near the edge showed that at least a final annealing was not applied, but a very careful re-etching produced "cores." The latter could not possibly have been in existence to-day had the vessel been hammered from a disc of metal, because the several annealings, which would have been absolutely necessary to prevent cracking during manufacture, would have made the metal homogeneous. It would seem, therefore, that the pot was at least cast roughly to shape and finished off by hammering. The flow lines in the grains may be a result of this, or they may possibly be due to grinding and polishing of the surface.

The microscope has also shown that, contrary to statements in various museum catalogues, the first Egyptians knew nothing of brazing or welding copper or bronze. Had such processes been known, they would certainly have been in universal use by the date of the Roman invasion. The general evidence in support of this contention has been discussed in a previous chapter; in this one we are only concerned with that given by microscopic examination.

The Roman pot mentioned in Chapter II. (Fig. 38) had been repaired during manufacture, two large holes having been filled up in the side. The method used has been described, but the photomicrograph (Fig. 84) shows a section through the repair.

The presence of the crystallites indicates that the added metal was molten; the crystallites are perfect in form, showing that no work was done on the metal after

casting. It was not, therefore, a piece of sheet metal put in as a patch.

Fig. 85 gives a photomicrograph of the joint between the pot itself and the new metal, unetched. It shows the lead globules; those on one side, that of the original vessel, are much larger than on the other side, which is the beginning of metal put in for the repair. The latter would solidify at a more rapid rate than the large mass comprising the pot did before it, thus preventing the lead running up into larger balls. From the structural

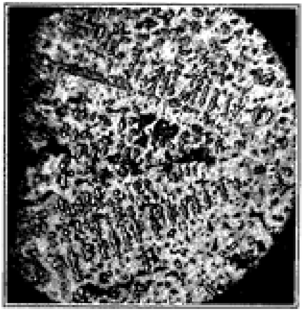

Fig. 84.—Microstructure of Repaired Portion of Roman Pot (Fig. 38).

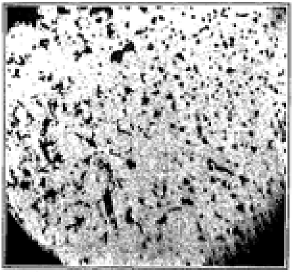

Fig. 85.—Microstructure of Joint in Repaired Pot. Unetched.

similarities of the two metals, it is probable that the repair was done at the time of manufacture. There was no trace whatever of brazing.

If the repair had been made by affixing a bronze plate and brazing it into position, as it would have been if brazing had been in general use, it would readily have been detected.

Occasionally microscopic examination indicates something of special interest in the metal used for a particular antique object. For instance, a bronze statuette was found to have been cast from scrap metal. The photomicrograph (Fig. 86) shows two small isolated fragments embedded in the bronze. These are pieces of copper, being easily distinguished as such by the appearance and colour on the etched surface. The twin markings, which can be seen running across one grain, indicate that they

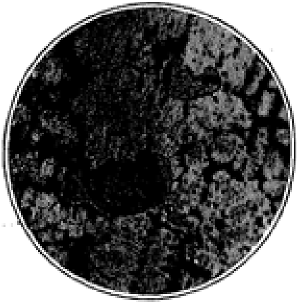

Fig. 86.—Microstructure of Bronze showing Inclusions of Unfused Scrap.

originally formed part of a piece of previously worked copper, perhaps an old tool, before being used in the bronze. They were not fused when the bronze was melted.

The corrosion of metals and alloys is a subject to which metallurgists of to-day are giving much attention. In modern experiments on corrosion the process is frequently hastened by electrolytic or other means, in order to obtain results within a reasonable time. We may learn something of its effects and progress from a

study of antique specimens, many of which, notwithstanding their great age, have withstood corrosion in a remarkable manner.

Some of the early bronzes in the state in which they are found, covered with a crusted mass of carbonates and oxychlorides, look most unpromising, and it is often a cause of surprise how, after careful cleaning, an antique object is found to be almost intact with all its original markings and inscriptions, almost as plain to the eye to-day as they were when first put on.

It is generally considered that all corrosion is electro-chemical in character, electro-couples being set up between the metal and its impurities, or between the different constituents forming an alloy. The presence of a liquid (often only moisture) is necessary to act as an electrolyte. This explains something of the selective nature of corrosion in metallic substances, but beyond asking the reader to bear the fact in mind, it will not be necessary to attempt any further explanation from this standpoint.

Metallic corrosion is selective and intergranular in its action, the second characteristic being really an effect of the first. It is generally known that all metals are not attacked to the same extent by the same corrosive elements. In an alloy the relative solubilities are to a great extent retained by the individual constituent metals, providing they do not form chemical compounds with each other. Thus, in a cast copper-nickel alloy the copper-rich parts of the structure are attacked more readily by an acid than the parts rich in nickel, or, to quote a case where complete mutual solid solubility does not occur, in copper-silver alloys the copper-rich parts of the structure are attacked more readily than those parts that are rich in silver.

Therefore, in a metal, containing little impurity, which is held in the intergranular boundaries, and which may be in the form of element, intermetallic compound, or oxide, corrosion proceeds more rapidly at these boundaries. This is one of the reasons why the etching of the surface of a piece of metal reveals the boundaries of the grains, and is a consequence of the electro-chemical nature of corrosion.

The copper dagger of the 1st Dynasty (previously described on p. 146) shows us something of the selective nature of corrosion. Owing to the entire oxidation of the sheath in which the dagger was originally contained, there was a crust of green copper carbonate, etc., about ¼ inch thick, surrounding the metal core of the dagger itself, which was in a surprisingly good state of preservation. In the space between the dagger and its sheath, on each side, the corrosion had been able to proceed in a more uniform and undisturbed manner than generally happened with these old metal articles, and it was possible, after removing the crust, to distinguish on the surface of the dagger the forms of crystallites in sunk relief due to their having corroded more rapidly than their arsenic-rich boundaries. The specimen was, therefore, at once recognised as being still in its original "cast-cored" state, and the interesting feature was photographed. Fig. 87 is a micrograph of the external surface; the light markings, the shapes of which, though somewhat irregular, are readily identified with crystallite formation, are the depressions left by the corroded copper-rich crystallites, but they were allowed to remain filled up with green cupric carbonate in order to afford some contrast for photographic purposes.

The forms of the crystallites could also be seen in relief

upon the pieces of copper carbonate crust removed from the specimen.

This selective oxidation was also detected in the interior of the metal. Near the edges of the section microscopic examination showed that the crystallites had entirely corroded, though their contours were not so well defined as the external ones. Fig. 88 is a section, the dark parts of which are the corroded crystallites.

In this case the chief impurity held in a state of solid solution was arsenic, and the parts of the microstructure

Fig. 87.—View of Surface of Copper Dagger, showing Selective Corrosion. Light parts are depressions left by corroded crystallites, filled with cupric carbonate. Magnified 30 diameters.

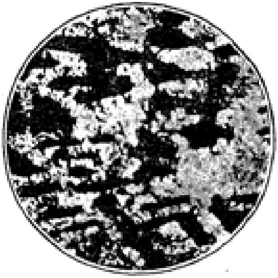

Fig. 88.—Section showing Internal Selective Corrosion near Surface. Dark parts are corroded copper-rich crystallites. Slightly etched. 10 per cent. ammonia persulphate. Magnified 50 diameters.

rich in this element were less readily attacked by the corrosive elements than the copper-rich parts.

Internal corrosion of crystallites is also shown in the photomicrograph of a copper graver (Fig. 89), the dark parts being the corroded crystallites.

Selective corrosion is very well shown by antique copper-silver alloys. The outer surfaces of copper-rich

antique objects made of alloys of these two metals, the natural colour of which is pale yellow, generally appear as white as silver when cleaned, and the true yellow colour is only revealed by filing. This is due to the removal of all the copper near the surface by corrosion. Fig. 80 shows how this takes place; it is a photomicrograph taken from the head of a statuette representing the god Osiris, made of an alloy of silver and copper containing gold. The section was not etched, but the corroded copper-rich primary crystallites appear black,

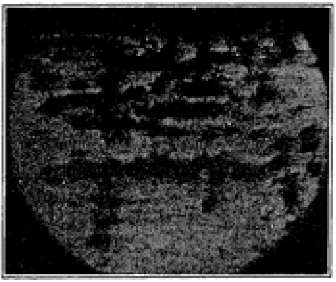

Fig. 80.—Microstructure of Copper Graver showing Corrosion.

due to the removal of the copper by solution and diffusion during corrosion.

Incidentally, this figure shows another feature that has been dealt with in a previous page in connection with the polishing of specimens for examination. In the portion of the photograph where the corrosion has not penetrated, the pink-tinted copper-rich crystallites appear, but this is not due so much to the fact that they differ in colour from the more yellow matrix, but because

the latter, being silver-rich, is much the softer of the two phases, and is, therefore, more worn away by the polishing, leaving the crystallites in slight relief.

Another specimen of a similar alloy showing selective oxidation is that of a piece of Coptic silver of poor quality. The microstructure, unetched, is given in Fig. 90, the corroded copper-rich crystallites near the surface appearing black, as in the previous specimen.

In order to show how a similar action occurs in alloys

Fig. 90.—Microstructure of Coptic Silver showing Corrosion. (Unetched. × 80 diam.)

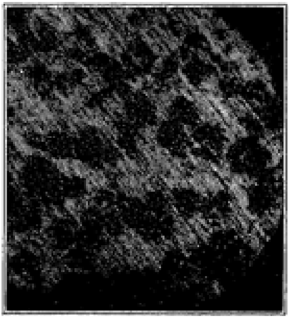

Fig. 91.—Microstructure of Silver-rich Alloy.

containing much silver and only a little copper, in which, as explained before, the primary crystallites are silver-rich, a photomicrograph (Fig. 91) is given of a section, unetched, of a small statuette of a god, the view being taken near the edge. In this case the primary crystallites are a solid solution of silver with gold, and most of the copper is held in the eutectic matrix. Thus we find the

oxidation has taken place in the latter phase of the microstructure. The dark mottled patches in the photomicrograph are the parts from which the copper has been removed by corrosion near the surface of the specimen.

The corrosion of the copper-rich portions of the microstructure may proceed towards the interior of a specimen to a considerable distance; it has been found in some silver-copper alloys to have reached a depth of a quarter of an inch, leaving the surrounding silver-rich parts quite

Fig. 92.—Microstructure of Copper Nail showing Corrosion.

intact and perfectly metallic. When a section is polished, this feature causes the outer edge round the unetched section, when viewed by the eye, to display a dull greyish appearance, whilst the inner, uncorroded metal of the core is bright and metallic. Etching, however, rather tends to reverse the visible effects, the inner portion, being still coppery, becomes dark through attack by the reagent, whilst the outer corroded ring, which contains very little copper, is not attacked, and so appears bright

and metallic in contrast with the etched interior. This may lead a beginner to think that corrosion had taken place internally, but the microscope quickly reveals the solid nature of the inner metal and the porous state of the outer ring or shell.

In the case of an antique copper or bronze specimen, which was heated soon after manufacture, and thus possessed a homogeneous structure of crystal grains without cores of any kind, corrosion has proceeded, not

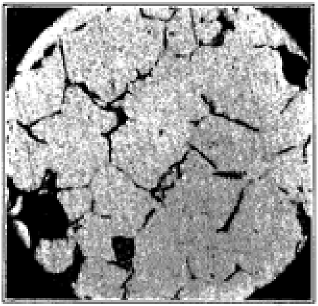

Fig. 93.—Microstructure. Axe Head showing Corrosion.

as a gradual eating away of the surface, layer by layer, but by traversing the intergranular boundaries, thus attacking the grains from all sides. Fig. 92 shows this. It is a photomicrograph of the structure of an XVIIIth Dynasty copper nail. The crystal grains, which are of a large order, are surrounded by dark bands where corrosion has proceeded between them, thus showing up the limits of the granular boundaries without etching.

Fig. 93 also shows intergranular corrosion that occurred in a copper axe head; the surface was not etched.

This intergranular progression also occurs when an annealed copper or bronze alloy has been afterwards worked and left in the strained state, but in these specimens it also traverses the new surfaces of parts of grains that have been made to slip over other parts of the grains of which they previously formed part—that is to say, it travels along the dividing planes between the portions of a grain that has been distorted or broken up by the "work." The visible effects of "work" upon the microstructure of an annealed metal are the flow lines which

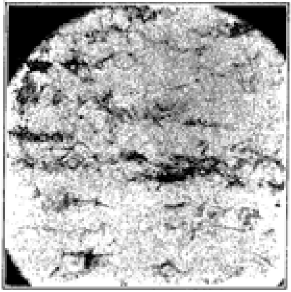

Fig. 94.—Microstructure of Roman Bronze Jar. Unetched (*Fig.* 83).

cross the grains and the generally crushed state of the crystal boundaries, all of which are brought into view by etching the surface. The visibility of these flow lines and crystal boundaries in an antique metal without etching shows that corrosion has taken place along the slip planes as well as the boundaries. The section of a Roman jar (Fig. 83) shows the effect very well. The photomicrograph (Fig. 94) was taken without etching

the surface and the many flow lines brought into view by corrosion alone are unmistakable.

There are many variable factors affecting the amount of corrosion, but the proportion of impurities present in the metal and the composition of the latter, if an alloy, are two of the most important. As an instance, the ancient Egyptian hinge (Fig. 95) may be quoted. This was originally fitted to a wooden door by two rivets, which were found *in situ* in their original position. The body of the hinge was made of poor metal, it was cast

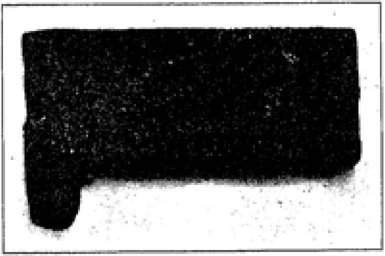

Fig. 95.—Egyptian Hinge (Bronze).

to shape, and contained a good deal of lead, but it was not intended to bear the same mechanical treatment as the rivets. The ancient metal workers, therefore, made the latter of much better material. They had to be hammered to shape, and afterwards riveted over at the ends. It is not improbable that they were forced through the wood by simply being made very hot; they contain practically no lead.

The body of the hinge was found to be extremely brittle: it broke readily with a hammer, but, after

thousands of years, the rivets are still very tough. The two photomicrographs (Figs. 78 and 96) show the differences in the microstructure. The rivet possesses a very fine, healthy, crystalline structure, but the metal of the body is traversed by "rivers" of corrosion, due no doubt, firstly, to impurities, and, secondly, to the fact that the metal was left in a cast, unannealed condition, and, therefore, in a state less homogeneous than it might have been. The quantity of lead present would itself tend to make the metal brittle.

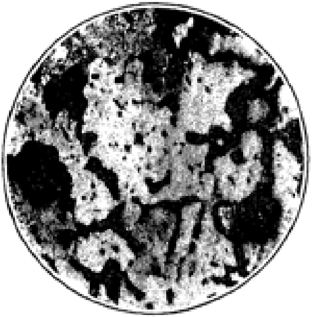

Fig. 96.—Microstructure of Hinge, showing Impurities and Corrosion. × 90 diam.

Fig. 97.—Microstructure of Bronze Arrow Tip. × 90 diam.

The photomicrograph of a bronze arrow tip (Fig. 97) also shows the selective action of corrosion, the black patches being crystallites entirely oxidised, leaving the matrix in bright metallic form. In this case the oxidised part of the structure is in excess of the unoxidised part (the matrix), and, therefore, the latter, although continuous, was too fragile to preserve the external contour of the object. Such cases are not of common occurrence.

The preservation of the detail and fine work upon old bronzes is due in a great measure to the selective and intergranular nature of corrosion. As the metal surface is not attacked layer by layer, as might have been supposed, the original form of the object remains largely intact, being preserved by the metal unacted upon, though, of course, the latter is very brittle, owing to the porosity thus produced by the selective nature of the corrosion.

The preservation of the external shape is well shown

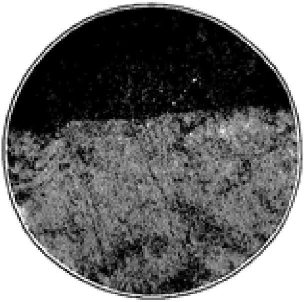

Fig. 98.—Microstructure of Roman Pot (Bronze). × 100 diam.

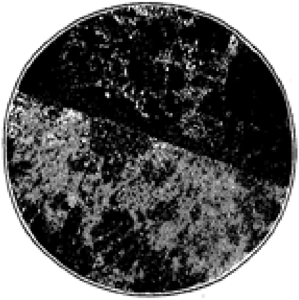

Fig. 99.—Microstructure of Bronze Arrow Tip. × 100 diam.

by two photomicrographs reproduced above. Fig. 98 is the section (unetched) of a Roman bronze pot, taken at right angles to the surface near the edge, with its green oxidised layer.

It shows the clear demarcation between the green oxidised crust and the metal (the lighter part). The straightness of the metallic edge after some thousands of years of corrosion, is worthy of notice. As was explained with reference to a previous photomicrograph

(Fig. 82) of this vessel, the metal itself shows flow lines due to "working," which are brought into view by the corrosion that has proceeded between the slip planes, of which these lines are the indication.

In Fig. 99 the division between the oxidised crust and the metal is even straighter and better defined. This is the photomicrograph of a section of a bronze arrow tip. Selective corrosion has taken place in the metal itself (the light half of the photograph), but this has not interfered with the general preservation of the flat form of the surface, as indicated by the edge.

The vagaries of corrosion are, however, very perplexing, and there is no doubt that during its course alternating processes of oxidation and reduction ensue. The metal still remaining as such will precipitate metal from solutions of certain soluble salts that may be formed around it, and other salts will, in the course of time, undergo a change into oxides by a process which may perhaps be looked upon as a natural reversion to the most stable form.

Some antique copper and bronze articles have a kind of warty appearance. The corrosion seems to have occurred chiefly in patches, and when the scabs of patina are removed by cleaning, holes are left. The graver shown in Fig. 100 is an example. In the photograph several holes can be seen on the surface. The cause of corrosion occurring in isolated patches in this way must lie in the nature of the surrounding material rather than in the substance of the metal itself.

Fig. 89 is a photomicrograph of a section of the metal through one of the holes, unetched. It shows how the crystallites were corroded well into the mass of the metal. For comparison a photomicrograph of a view

taken towards the interior of the metal is given (Fig. 101). In this the structure was developed by etching.

The nature of the surrounding material in which an

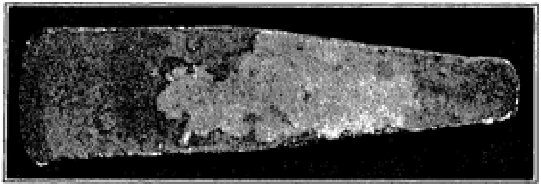

Fig. 100.—Egyptian Graver.

article lies in the earth will have a preponderating effect upon the nature of the salts that are formed: in some cases it will be chiefly carbonate, in others chloride or

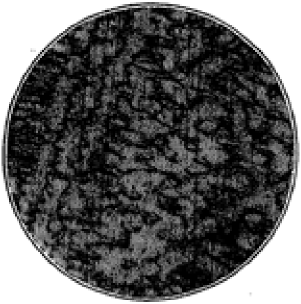

Fig. 101.—Microstructure of Graver.

oxychloride, whilst in others cuprous oxide, but never cupric oxide (except in cases where objects have been

burnt in a fire) will predominate. Under the green carbonate crust generally found on old bronzes, and which may be any thickness from a thin skin to a quarter of an inch or more, there is often found a very regular layer of cuprous oxide, in which the fine details of the object appear to be preserved, and consequently the removal of this layer means the loss of the detail, but the layer may sometimes be removed without damage to the work.

A particularly interesting case is the bronze mirror, of which a photograph is given in Chapter II., p. 71. On the outside of the specimen there was a rather warty crust of green salts; under this a very thin skin of cuprous oxide, and under the latter an unevenly distributed layer of grey copper and tin oxychlorides.

A remarkable feature was that the thin film of cuprous oxide had preserved a good deal of the polish that had originally been applied to the metal surface of the mirror when made. In the illustration an attempt has been made to reproduce this polish as it reflected the sun's rays. This causes the polished parts to appear white in the photograph. The darker patch is a portion of the outer green crust which had not been removed. It is strange that the polish originally possessed by the bronze surface should be preserved in spite of the fact that the latter has undergone a gradual conversion to oxide. Fragments of pure precipitated copper, bright and tough, were found amongst the green crust on this mirror, and a description of their microstructure will probably be of interest to metallurgists. The fragments were very small and fragile; the largest piece was less than ¼ inch square. A photograph of a fragment is given in Fig. 102. It will be understood that to prepare a polished surface, to etch it, and to mount a specimen

of this size, was not an easy matter, but a method that the author had previously used with very small fragments of gold was found to suit admirably. A cartridge case was filled with a fusible alloy melting in boiling water, and, whilst this was still molten, the copper fragment was laid carefully on the surface and held whilst the alloy solidified round the edges. This held the copper sufficiently tight for polishing, which had to be curtailed

Fig. 102.—Fragment of Copper from Corrosion Product.

Fig. 103.—Microstructure of Fragment of Copper (Fig. 102).

somewhat, as such a thin specimen would soon be wholly ground away.

When polishing was completed a steel point was inserted under the edge of the specimen, and the latter was lifted away, the embedding alloy not having a sufficiently tenacious hold to prevent this. Afterwards, the etching and washing were carried out in the usual

way and the specimen mounted by means of plasticine upon a glass slip.

A photograph of the microstructure is given in Fig. 103. The author was somewhat surprised to find twinning and the secondary type of granular structure with grains of a large order. Sensibly parallel lines will be seen running across the grains, and these the author presumes to represent the boundaries of different layers deposited upon the grain from time to time. They may possibly be slip-bands brought about by straining during preparation of the specimen.

Analysis proved the specimen to be pure copper. It would seem that this copper was precipitated during corrosion from the concentrated salts of the metal by the metallic unchanged bronze, and no doubt the same obscure causes that produce twinning in the structure of electrolytic copper were operating in this case also.

It has been explained that small quantities of metals present in copper or bronze that are insoluble in these metals when solid, will, by existing in the free state as globules or layers, tend to set up electro-couples with the surrounding copper-rich metal, and thus the alloys will be liable to rapid corrosion and disintegration, but their effect may be to draw away the corrosive effects from the copper to themselves.

The arrow tip, of which a photomicrograph is given in Fig. 104, contained a considerable amount of lead, and this, of course, occurred in the microstructure of the bronze as isolated globules, but in one-half of the photograph they are black, whilst in the other they appear in half-tone. The explanation of this is that the black globules are those in the interior of the mass still metallic and intact, but the grey ones are those near the surface that were oxidised and appear pale blue in

colour on the microsection, whilst the bronze by which they are surrounded is still bright and metallic. The photograph is included in order to show how in such cases the corrosion selectively attacks the lead globules in preference to the bronze that surrounds them.

It should be remembered that antique Egyptian coppers and bronzes generally contain varying amounts of iron. In specimens left in a cast, "cored," state of microstructure, the iron being in some parts concentrated, the rate of corrosion must be more rapid than in

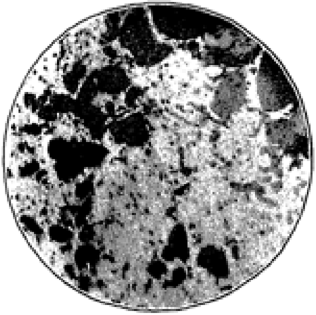

Fig. 104.—Microstructure of Bronze Arrow Tip.

others that were thoroughly annealed, and, therefore, hold their iron diffused evenly through the mass.

For the information of archæologists and collectors, we may mention that the internal structural corrosion of metals is an unfailing guide as to the authenticity of doubtful antique copper, bronze, and silver objects. Imitations of antiquities of all kinds have been brought to a high pitch by unscrupulous persons, but although external corrosion patinas may be skilfully copied, no

practical process can be applied to metal objects that will reproduce the extensive internal corrosion found in examples of genuine antique origin. It is also not improbable that, when the subject has been further studied, it will be possible to state, within reasonable limits, from the extent of the internal corrosion, the actual age of a given article, and this may be of considerable use in cases where it is desirable to approximately fix the period to which the article belongs when the same is in doubt.

All antique bronze objects are brittle; some of them can be pounded with a hammer. In some cases this brittleness is partly due to impurities, such as lead and bismuth, but, as a rule, it is the result of the selective and intergranular progression of corrosion. Copper articles usually retain much more of their original toughness than bronze ones; they do not, as a rule, contain metallic impurities that would increase their fragility when new. Antique silver articles containing copper are also brittle, owing to causes previously explained, but silver that is almost pure, or which only contains gold, is well preserved, except that sometimes in the case of thin articles found in Egyptian soil an almost complete conversion to argentic chloride has taken place. Gold objects retain their original toughness, as the metal is not subject to corrosion. If, however, it contains much silver, selective attack takes place, and a crust of silver chloride is found upon the surface.

CHAPTER VI.

NOTES FOR COLLECTORS OF ANTIQUE METAL OBJECTS.

(1) Cleaning and Preservation.

Amateur collectors and others interested in antiquities often find themselves in need of some notes upon cleaning and preservation of objects. A valuable bronze or other metal curio is likely to be irretrievably ruined by injudicious experiments on cleaning or the application of an unsuitable process. In the previous chapter we have dealt with the more scientific aspects of the causes and effects of decay, and this one will be devoted to hints on the means of investigation, the methods of prevention of decay, and on the processes of repair available to the collector who has not an extensive laboratory at his disposal.

Almost the first difficulty met with by the collector is the cleaning of bronzes. Unless they have previously been cleaned by a dealer, these bronzes invariably have a green or blue oxidised crust of a thickness that varies with the age and place of inhumation of the object. This crust, usually alluded to as a patina, is not, as is sometimes supposed, pure verdigris (carbonate of copper), but is of varying composition. On Egyptian bronzes it consists largely of oxychlorides of copper, due to the fact that Egyptian soil is rich in salt (sodium chloride). Under the green patina there is usually found a thinner

coating of red oxide of copper, which is in contact with the bronze itself. In badly oxidised objects all the metal is found to have undergone the change to cuprous oxide and the green patina.

The means for the removal of the patina that comes naturally to the mind of a person still remembering the chemistry of his school days is the use of an acid, but it is necessary to exercise much caution in applying such processes to metals of great age. Unlike modern metals and alloys, all old metals are more or less porous owing to the corrosion; this, besides rendering them fragile, also makes them far more susceptible to attack and disintegration by corrosive substances.

In some museums, especially German ones, bronzes have been cleaned electrolytically. The object is immersed in an electrolyte consisting of a weak solution of potassium cyanide, a feeble electric current passed from a battery which breaks down the chlorine compounds forming the patina.

The method is applied, with suitable modifications, to the cleaning of objects of other metals, but it is much too elaborate for the ordinary collector's use, and indeed the other simpler methods, over which it has no salient advantages, will be found equally satisfactory.

In some cases where the patina is very thin and of agreeable appearance, not masking the fine detail of the piece, no cleaning is necessary, but it is essential that such specimens, and indeed all metal objects, be kept in as dry a position as possible, never being allowed in a room where acid fumes are liberated, and not touched with the fingers any more than is absolutely necessary. In order to prevent, as far as possible, further corrosive action by the atmosphere, all metal articles are usually impregnated by immersion in molten paraffin wax, the

surplus wax being wiped off. The leading German authority, Dr. F. Rathgen, however, recommends, instead of impregnation with wax, the painting of the outside with a preparation called Zapon, a solution of nitrated cellulose in amyl acetate. This gives a thoroughly waterproof coating to the bronze, which is not too glossy in appearance if thinly applied, but it is necessary to give a warning against a too general use of this preparation. In addition to the defect of extreme inflammability, the gelatinous nitrated cotton (guncotton) is liable in the course of time to decompose spontaneously and to liberate free acid. This must be injurious to antique metals, but the process of decomposition is slow, and the Zapon method may not yet have been in use sufficiently long for the defect to have become apparent. An ideal substance for the impregnation of metal objects should obviously be distinctly and permanently neutral—that is, neither acid nor alkaline. The wax method of impregnation is, however, in more general use, and, so long as care is taken to keep the wax free from acid it will be found to satisfy all requirements. It is advisable to test the molten wax with litmus paper before use.

It is possible to remove the green crust from many bronzes by mechanical means, and this is obviously the method par excellence, because there is no immersion in acid or other liquid, but it requires great care and patience to avoid damage to the detail. The patina flies off in small chips under suitable sharp taps from a little hammer, the face of which is chisel-shaped, but has a fairly blunt edge. A little practice soon shows the most suitable angle for the blow.

This method is a favourite one amongst curio dealers, who are always anxious to clean their objects without the risk to the subsequent preservation that immersion

in any liquid entails. Mechanical removal of the patina leaves the object with the pleasing dull brown-red colour of cuprous oxide, which seems as if it must be permanent. It must be remembered, however, that cuprous oxide is much more readily attacked by corrosive substances than metallic copper itself, and, therefore, articles cleaned in this way are not immune from further corrosion which may be brought about by the carbonic acid in the air, thus producing verdigris, or initiated by chlorides that may be present in cracks, etc., in the metal, thus producing oxychlorides on the surface; but it may be stated, however, that the possibility of subsequent corrosion or decay taking place, is much reduced when bronzes are cleaned by mechanical means, provided care is taken not to handle them with the naked fingers during manipulation, and if they are impregnated with wax immediately after removal of the crust.

Bronzes for mechanical cleaning must be fairly solid, and must have a good foundation of metal. Therefore, the specimen should be well examined to make sure that the whole of the metal has not been oxidised.

Some bronzes cannot be cleaned mechanically, and for these chemical or electro-chemical means must be used. Great care has, however, to be exercised in applying them. Any of the common acids might be used as a solvent for the patina, but hydrochloric acid is much the best, because it has the least action upon metallic copper; in fact, the metal is generally regarded as insoluble in this acid. It is not, as a rule, advisable to use it stronger than a 5 per cent. aqueous solution, and during the immersion of the bronze, the latter should be frequently examined and brushed with a hard bristle brush. This removes bubbles of hydrogen which cling to the surface, and also clears away any insoluble salts,

earthy matter, etc., that may be impeding the further action of the acid. It is important that the whole article be immersed at one time.

In some cases there are patches of patina which resist the action of the acid, and these should be removed mechanically with a knife or small hammer after drying. The specimen must be taken out of the acid bath as soon as there appears to be no further action on the patina. It is useless, and indeed very detrimental, to keep the bronze immersed in acid for a longer period in the hope of removing obstinate patches, which may be quite insoluble.

It is much better to place the object in 5 per cent. or even stronger acid, with frequent examinations and brushings, than to leave it overnight or for days in a much weaker solution without examination.

After removal from the acid bath, the bronze has generally a white coating of copper oxychlorides, which, however, disappears in the further stages of the cleaning treatment. Much of it is removed by a final brushing after removal from the acid bath.

If the object were simply dried it would speedily turn green again, and active corrosion would speedily recommence. It is, therefore, necessary to remove all traces of acid as far as possible, and this is best done by first rinsing thoroughly in water and then boiling for half an hour in water containing 0·5 per cent. of soda. This turns the colour of the surface to a rather bright red, which is unpleasant, and should be removed by brushing. The object should next be washed in running water for an hour or longer, and afterwards dried by heating it for an hour at about 160° F. to expel all moisture, and then should be impregnated with paraffin wax by immersion in a bath of this material heated until

white fumes begin to rise, the superfluous wax being afterwards allowed to drain off.

For articles of a thin nature, as, for instance, many hollow statuettes which were cast on a core, in which the metal exists now mainly as cuprous oxide, no method of cleaning will be of service: immersion in acids would disintegrate them, and they would not, as a rule, withstand mechanical removal of the patina. In some cases acid treatment would give a temporary improvement to the outer appearance, but the acid, by permeating the porous core, could not be completely removed afterwards, and further corrosion would be certain to ensue. In one specimen examined, the metal was extremely thin and much oxidised, and would certainly not have survived until to-day had it not been supported by the core, which it would now be a mistake to remove. For such bronzes, the only possible treatment is to remove such patches of patina and earth as can be easily moved with a knife and impregnate with paraffin wax.

Care should be taken not to handle with bare fingers specimens during cleaning, and indeed at any time previous or subsequent to impregnation with wax. It is advisable to wear gloves, and these also have the desirable property of preventing the green tinted finger nails which are the despair of amateur collectors who do much of this work.

Immersion in ammonia after the acid process is not recommended. It dissolves the cuprous oxide very readily, thus often removing much of the finer detail, and leaves the surface with a bright, metallic appearance, which is not pleasing. In some cases its application would quickly ruin the specimen.

Fig. 105 shows an uncleaned statuette (Græco-Roman period) with its thick green incrustation, whilst Fig. 106

is a photograph of another similar Greek statuette cleaned by the hydrochloric acid process. The Egyptian bronze

Fig. 105.—Uncleaned Statuette as found.

Fig. 106.—Cleaned Statuette.

mummy eye was also cleaned in this way (Figs. 107 and 108).

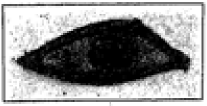

Fig. 107.—Uncleaned Mummy Eye.

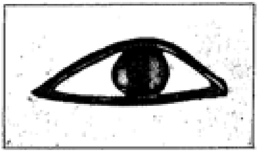

Fig. 108.—Same as 107, after Cleaning.

A part of the bronze mirror (Fig. 35) was cleaned by chipping with a small hammer, the little chips of patina flying away readily under sharp glancing blows, leaving a thin oxide film with a glossy surface.

It is a great mistake to attempt to apply artificial patinas to cleaned antique bronzes. The extensive corrosion prevents the satisfactory application of any of the processes used for colouring modern alloys.

Acetic acid in the form of vinegar may be used for bronze cleaning with the addition of a few fragments of zinc, and in this method the action is an electro-chemical one, a voltaic cell being formed by the zinc and copper in contact, but it has no advantage over the hydrochloric acid process described. Neutralisation in weak soda solution and thorough washing are equally as necessary.

Instead of vinegar, a weak solution of caustic soda is sometimes used, and there is, therefore, in this case, no free acid in the bath, but other compounds are formed which are just as detrimental and must be thoroughly removed by washing. The zinc and copper, too, must be in actual metallic contact, which is not always easy to arrange.

If the collector would give a bronze the best chance of future preservation, he must endeavour, first, to clean it by mechanical means under the precautions laid down previously as to handling, and if this does not prove satisfactory, he should apply the hydrochloric acid method, taking care afterwards to remove all traces of acid, and to impregnate it immediately the cleaning and drying is finished.

A word of warning is necessary with respect to the cleaning of bronze articles having iron attachments. For instance, some little bells have iron wire hammers. The latter, however, are entirely oxidised, and exist as

a barely coherent string of oxide. Cleaning the specimens by any immersion process would be certain to ruin them, and if it is found necessary to clean the bronze, the iron might be protected by painting paraffin wax upon it before immersing, even then, however, it should be considered whether the removal of the bronze patina would not loosen the iron fittings. Unless there is some important reason for attempting cleaning, it would be better to leave such compound objects in their uncleaned condition, and simply impregnate them.

Bronze statuettes are often heavily inlaid with gold and silver. In cleaning these objects there is a great danger of disturbing the inlay owing to the attack of the cleaning medium beneath the gold or silver wire. The author has seen some superb examples of this class of work cleaned by hydrochloric acid, but when dealing with such articles very frequent examination is necessary during immersion, and the object must not be left in the liquid a moment longer than is necessary.

It is, unfortunately, sometimes found with bronzes that have been carefully cleaned, and even some having only a slight patina, and, therefore, not cleaned, that some time after being placed in the collection, light green patches of corrosion, of an efflorescent nature make their appearance on the surface. It is not necessary to recapitulate all the possible causes of this, for they are many, but it will be obvious that bronze objects that keep well in a dry climate will probably not do so in a damp one, or in an atmosphere charged abnormally with carbonic acid or with the salt sea breezes of a seaside situation. Impregnation with wax does much to prevent further corrosive action of this nature by filling up holes and pores, thus preventing access of moisture and vapours to the interior, but it does not in any way

neutralise any corrosive elements which may be present within the metal or core, having penetrated during the time the bronze was buried, though by preventing diffusion it may retard the decay of the metal in a marked manner. The only method of any service is to brush off the patina, which is floury and non-coherent, with a fairly hard brush, remove as much of the paraffin wax as possible by heating the specimen, and soak the latter in water containing 10 per cent. of soda for two or three days, periodically examining it and afterwards brushing and rinsing it thoroughly in water, drying and impregnating again with wax.

Practically nothing can be done with regard to cleaning bronzes of which the metal is wholly oxidised. These are generally thin articles such as bowls and other vessels, and hollow statuettes, etc., cast by the cire perdu process upon a core. Beneath the green crust there is a stratum of cuprous oxide with grains of metallic bronze or copper embedded in it, and the latter give an erroneous impression of solidarity when the surface is filed. A microscopic examination which shows extensive intergranular corrosion (described in Chapter V.) penetrating far towards the middle is sufficient evidence that it is quite useless applying any cleaning process, as the mass which is more or less cemented together would only crumble away as the more soluble parts were dissolved by the acid, or were broken down if an electrolytic process of cleaning were applied. Articles in this state are, however, very permanent, and impregnation will retard further corrosion, but there is always the possibility of further changes in the cuprous oxide, as it is so readily converted to copper carbonate (verdigris) by the carbonic acid in a damp atmosphere.

It is certain that many of the bronzes in our collections,

in spite of the great care which is taken to preserve them in some instances, will not last to another period of time equal to that during which they were buried in the ground, and it may not be out of place to mention some of the causes that have contributed to their preservation up to the present time. Primarily, we must remember that subterranean corrosion is very much slower than aerial corrosion, but many of the Egyptian bronzes, which, of course, include many of the oldest specimens in existence, when made, were coated with plaster and coloured, in spite of the excellent workmanship applied to the metal. Figs. 25 and 26 are examples, in which the pittings in the surface of the bronze, in order that the plaster should adhere, can be seen. It represents the god Osiris, but the face was not covered with plaster, as the eyes were inlaid with gold. The plaster coating would probably act as a preservative for centuries. Again, other objects were gilt, and gold being so resistant to corrosion, it preserved the bronze from corrosion until the action was able to undermine it by penetrating the various isolated cracks and patches of ungilt parts that existed on each specimen.

According to the testimony of Plutarch, other Egyptian bronzes were oiled, in order to produce a pleasing patina, and this would also have a protective action for some time. In different degrees these various coatings upon bronze objects would act as preventives of corrosion, but, of course, their effectiveness would be dependent upon the care with which they were applied and to the treatment the objects received during use. Possibly this is one of the reasons that the greater part of the bronzes preserved until the present time consist of statuettes and other devotional and decorative objects, as the coatings would obviously not be applied to copper and bronze articles intended for useful purposes.

It does not often fall to the lot of the average collector of Egyptian antiquities to have to clean silver articles, but occasionally little statuettes up to three inches high and other articles such as finger rings come to hand. They are coated with a patina of silver chloride, which, though normally white, has turned black by the action of light. They may be cleaned by immersion in ammonia, thorough washing and drying, and afterwards impregnated, but if the patina is thickly crusted and warty, especially if the object is thin, the whole metal has probably undergone conversion to chloride, and in that case it would be disastrous to attempt to clean it. It should simply be relieved of any adherences of earth that can be removed with a knife without damage to the form of the object, and then impregnated.

As a general rule, however, most metal objects containing silver, also contain copper, and thus they carry a green patina, which causes them to be mistaken for bronze objects, and to be submitted to the acid cleaning process, which, of course, is the most suitable, ammonia not being a desirable cleaning agent for old metals containing much copper. The author knows a collector who obtained for a shilling or two, three statuettes, unrecognisable in their thick green crust, which, after cleaning, proved to be rich in silver, of excellent workmanship, worth some pounds each.

Objects of lead are scarce, but sometimes statuettes, removable head-dresses, intended for fitting on bronze figures, etc., are found, as well as a number of coins of Græco-Roman times. They are covered with a yellowish coating of carbonate of lead, which, however, is thin, and the corrosion does not penetrate into the interior of the metal. The coins especially are often wonderfully well preserved considering the softness of the metal.

The objects may be cleaned in dilute sulphuric acid, 5 per cent., which converts the carbonate into sulphate, and can be easily brushed off, or the hydrochloric acid process as used for bronzes may be used. In either case, neutralisation for a few minutes in water containing ½ per cent. soda is necessary, followed by thorough washing and impregnation with wax.

Antique iron objects are scarce in Egypt, but it may be necessary at times to know of a cleaning process. First of all, it must be said that unless the collector is absolutely certain that there is a substantial stratum of metal beneath the oxidised crust, he must not attempt to remove the latter by cleaning. It is unlikely that any Egyptian objects dating back previous to 1000 B.C. will be sufficiently well preserved to withstand any cleaning process. The loose scales on the outside may be removed mechanically, and the specimen afterwards thoroughly boiled in water, dried, and impregnated with paraffin wax.

Iron objects of later date may possess a metal core of a substantial size, but obviously hydrochloric acid cannot be used, as it so readily attacks metallic iron. Probably the best method of cleaning is that of Krefting, in which the specimen is immersed in a 5 per cent. solution of caustic soda in contact with zinc. Thorough washing is afterwards necessary, then the specimen should be dried and impregnated.

The cleaning of gold objects is not difficult, as they are usually well preserved. Brushing with water is, as a rule, sufficient, or, in the case of electrum, there may be a deposit of silver chloride, which will need ammonia for its removal.

It is advisable to keep metal objects separate from one another in collections, in order to prevent decay being

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communicated. This is not always done in our museums, some of which are very crowded.

With regard to artificial patinas that the ancient Egyptians may have sought to produce upon their bronzes, it would seem that, in view of the numbers of statuettes that were gilt or covered with plaster, and the absence in the alloys of intentionally added lead in the earlier dynasties of which examples now exist, they did not endeavour to influence the nature of the patina by modifications of composition. They would, of course, be well aware of the differences of colour produced by adding various amounts of tin to copper, of silver to gold, and of copper to silver, but whether they eventually added lead to bronze to produce certain types of patina, or simply to cheapen and ease the working of the metal, there is nothing to show. There is, however, evidence that great pains were taken in later times to produce pleasing colour effects upon the works in bronze, and the Egyptian statues received the admiration of the Greeks. It is not without interest to quote the following passage from "Plutarch's Morals" (translated by Mr. C. W. King, M.A.), which shows that the surface of the bronze was oiled and left exposed to the atmosphere, which together gave a result that drew admiration from men who were acquainted with the choicest works of art of ancient Greece.

"The sight and artistic merit of the statues did not so much attract the notice of the visitor, who had in all likelihood seen many fine things of the sort elsewhere; but he admired the colour of the bronze, which was not like dirt or verdigris, but shone with a dark blue dye, so as to contribute considerably to the effect of the statues of the admirals (for he had begun his round with them), standing, as they did, sea like, as it were, in colour, and

truly men of ocean deep. Had there been then, he asked, some mode of alloying and preparing the bronze used by the ancient artificers, like the traditional tempering of swords, which process being lost, then bronze obtained exemption from all warlike employments? For it is known that the Corinthian metal acquired the beauty of its colour, not through art, but through accident, when a fire consumed a house containing a little gold and silver, but a great quantity of bronze stored up there, all which being mixed and melted together, the preponderating part, by reason of its largeness, originated the name of bronze."

"What then," asked Diogenianus, "do you say has been the cause of the peculiar colour of the bronze in this place?" and Theon replied—"Inasmuch as of the greatest and most natural things that are and shall be—namely, fire, water, earth, air—there is not one that comes near to, or has to do with the bronze except air, it is clear that the metal has been thus effected by this element, and has acquired the peculiarity which it possesses by reason of this being always about it, and pressing upon it; you know, surely, that this once took place in the case of Theognis, according to the comic poet? But what property the air has, and what influence it exerts in its contact with the bronze—these are two things, Diogenianus, that you desire to learn?" and upon Diogenianus assenting: "So do I, my dear boy; therefore, if you please, let us investigate the matter in concert; and as a beginning—for what reason does oil, above all other liquids, coat bronze with verdigris, for it does not generate the verdigris simply by being rubbed over the metal, because it is pure and clear when applied to the surface." "By no means," replied the young man, "does this seem to me to be the reason;

but because the oil being thin, pure, and transparent, the verdigris falling upon it, is very perceptible, whereas in other liquids it becomes invisible." "Well done, my dear boy," said Theon, "but examine, if you please, the reason that is assigned by Aristotle." "I wish to do so," replied he. "Aristotle, therefore asserts that verdigris, if put upon other liquids, runs through them and is dispersed, because they are porous and fluid, whereas it is arrested by the solidity and density of the oil, and remains collected in a mass. If, therefore, we can ourselves devise some hypothesis of this kind, we shall not be entirely at a loss for some charm or cure against the present difficulty."

"Thus then," said he, "did we pronounce and agree, that the air at Delphi, being dense and compact, and receiving tension from the repercussion and resistance of the surrounding mountains, is at the same time biting and penetrating, as the facts about the digestion of food clearly evince; this air, then, by reason of its subtile quality, enters into and cuts the bronze, and so scrapes off verdigris in plenty, and that of an earthy nature, which again holds suspended and compresses, because its own density does not allow of its unlimited diffusion, but on the contrary permits it to settle down by reason of its abundance, and to bloom, as it were, and get brilliancy and polish over the surface," and upon our admitting this, the visitor said the one supposition (of the density) was sufficient for the explanation. "The subtile quality," said he, "would seem to contradict the asserted density of the air; and it is assumed without any necessity; for the bronze does of itself emit and discharge the verdigris, whilst the density of the air compresses and thickens it, and makes it visible in consequence of its abundance."

Some of the reasoning as to the properties of oil and verdigris may seem to us quaint, but the article makes it clear that patinas were produced, not by immersing the metal in acid or special chemical solutions as we do to-day, but simply by applying an oil over the surface and leaving the atmosphere to do the rest.

(2) Repairing.

The collector occasionally finds it necessary to repair bronzes. A statuette may be broken or incomplete when obtained, or a breakage may occur during cleaning, and although the collector himself will probably not be in a position to do metal working himself, it is well that he should know the general principles upon which it should be done when dealing with antique specimens, as the jeweller or artisan to whom he many entrust the job, although perhaps perfectly skilled in his craft, may be quite at sea when treating fragile objects of great age.

With the exception of some gold and a little copper work, no ancient Egyptian metals and alloys retain any of their original toughness. The majority of specimens are absolutely brittle, and will withstand little or no mechanical treatment. This brittleness is not wholly due to corrosion, but in some cases, also to the original composition of the metal, such as copper and bronze containing bismuth, or gold containing bismuth. The filed surface is often very misleading, giving a bright metallic appearance even when intergranular corrosion has permeated the mass and rendered it exceptionally fragile. In some cases the form of the fracture gives a better guide as to the state of the metal than the filed surface: the specimen does not bend at all, but snaps,

leaving the fractured surface dull red in colour, or sometimes grey if much lead is present.

When about to do repairs, the chief point to remember is, therefore, that all old Egyptian metal objects are fragile, and should be treated with extreme care. The methods of repair must be very cautious ones, and it is always wise to ascertain that the workman realises the extreme fragility of the metal notwithstanding its apparent sound appearance externally.

The types of repair that most frequently occur are the joining of two or more broken parts, such as a damaged leg or arm of a statuette, or the casting and fitting of a new part to replace one broken off or lost, in order that the object shall have something approaching its original appearance.

For making joints, it would be obvious that brazing is out of the question, because of the high temperature employed, which the old metal would not resist. Soft soldering can sometimes be used, but owing to the oxidised state of the bronze or copper, the solder often does not hold, and, therefore, makes a poor jointing medium for this work. Also, the solder being of a very different colour from the bronze, it is not easy to make it inconspicuous. Almost any acid painted on the solder in the joint will make it black, but it must be carefully applied, and the specimen afterwards well washed, dried, and impregnated with wax.

The fluxes generally used for soldering bronze and brass are zinc chloride and borax. For antique objects, probably the last-named is the least objectionable.

The repairing of small statuettes under about 6 inches high requires more skill and care than work on larger specimens, because an error in the jointing of even so little as $\frac{1}{32}$ inch is sufficient to disturb the anatomical

correctness of the modelling, and many of these figures, although so small, are exquisitely proportioned. Thus a layer of solder intervening the fractured surfaces of a limb would be sufficient to make the repaired leg too long unless the figure were a rather large one. On the whole, the soldering of joints is, however, not recommended for several reasons. Firstly, as explained previously, soft solder adheres very imperfectly to old bronze and copper; secondly, soldering entails the use of fluxes which are of a chloridic or acid nature, and are, therefore, liable to initiate further corrosion of the specimen; and, thirdly, soldering is not at all easy to do neatly and to render invisible afterwards.

When the fracture is a recent one, the two broken surfaces can generally be fitted together quite closely and correctly, and if a very thin cementing medium be used the joint is barely perceptible. Very thin mediums, however, have not the advantage of great rigidity, and the repaired specimen would not stand much handling afterwards. In many cases, the jointing of such fractures by a solution of shellac in methylated spirit will suffice, or with seccotine, although the latter is not waterproof.

As a rule, broken articles should be thoroughly cleaned before repairs are taken in hand, and to insure that fractured surfaces will afterwards fit together correctly they should be protected from attack by the acid, and for this a little molten wax can be brushed over the surfaces.

Whenever possible, it is advisable to give additional strength to the joint by fixing a central pin to connect the two parts, a hole being carefully drilled in each piece and the pin cemented or wedged in.

The fragility of antique bronzes renders attempts at absolutely perfect jointing unnecessary. For instance,

in the case of a hollow statuette broken into two parts, the filling up of each with plaster (removing any core present), and a substantial central metal pin connecting the two, would do, the crevice round the joint being filled in afterwards with a cement of similar colour to the original metal.

Alloys of low melting point, such as those that melt in boiling water, would seem to possess advantages for filling up broken and damaged bronzes, but they should not be used, as they invariably contain bismuth, which causes the alloy to expand during solidification, and this would probably crack or break the old bronze. The author has successfully used a dental amalgam of mercury with 25 per cent. cadmium for such work; it melts in boiling water, is plastic when warm, and sets very hard afterwards.

A bronze of superb finish or much interest is often marred by a deficiency of some part or limb that has been broken off and lost; the time and money spent in fixing another one is well spent, but the operation is one requiring some care and skill, more especially because an intimate acquaintance with antique works of art is sometimes necessary in order to insure that the new part shall be correct in form. It should, of course, be remembered that with collectors the object of making such replacements is not to deceive the beholder, but merely to render the specimens as complete as they were in their original state, and it is, therefore, necessary that the added parts should be similar to the originals both in colour and in the state of the surface of the new metal.

In such a repair, the first point to decide is what metal to use for the new part. The answer is—an alloy of a composition approximating to that of the original. For instance, for a copper object use copper, and for bronze

a copper-tin alloy, though for the latter copper would do also, and for brass a copper-zinc alloy. It is not desirable to use brass for an addition to a bronze object, as the patina of the latter cannot be so readily imitated upon brass as on bronze. The new part should be cast with a rough surface similar in appearance to that of the original, so that when coloured there will not be a great difference in outer appearances. This is easily arranged for in moulding.

It will generally be necessary to file off the broken surface of the fracture, so that the joint will be a flat one. Before jointing, the new part should be coloured to match the original as nearly as possible, and below is a list of processes which are available for producing various colours on different alloys :—

MODERN PATINA PRODUCING PROCESSES.

Colouring Brass.

Method A.—Olive green.

Red ammonium sulphide, ...	5 fluid ozs.
Water, ...	1 gallon.

Warm and immerse the object.

Method B.—Green.

Water, ...	1 gallon.
Salammoniac, ...	¾ oz.
Cream of tartar, ...	1¾ oz.
Salt, ...	3 ozs.
Nitrate of copper, ...	1½ oz.

Method C.—Black.

Dissolve as much copper as possible in strong nitric acid. Dip the article, and then heat strongly but gradually; allow to cool slowly.

Colouring Bronze and Copper.

Method D.—Brown to black.

Liver of sulphur, ...	½ oz.
Water, ...	1 gallon.

The length of time of immersion or heating the solution affects the depth of the colour.

Method E.—Black.

As method C for brass.

Note.—Metals for colouring must always be cleaned and freed from grease, etc., by dipping in a solution of 4 ozs. potassium cyanide in a gallon of water, then washed before immersion in the colouring bath. Specimens must not be touched with the bare fingers. If the first attempt is not satisfactory, dip again.

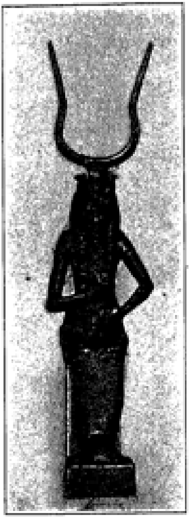

Fig. 109.—Repaired Statuette of Isis.

A repair was made to the statuette of the goddess Isis shown in Fig. 109. When received the figure was minus feet and legs, the bottom portion having been broken off from the knees and lost. Luckily a spare

pair of feet that had belonged to a similar statuette were at hand, and it was, therefore, only necessary to make a casting of the remaining portion of the legs. This was done in bronze, afterwards blackened to match the original by the use of Method C. The joint was

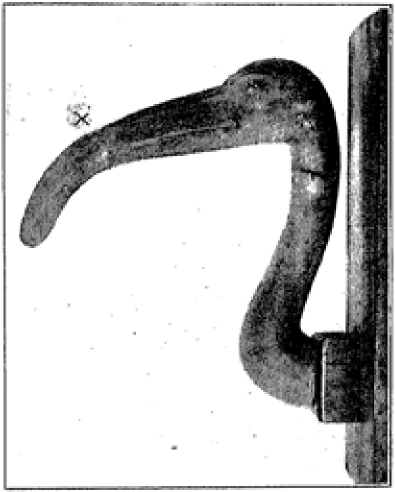

Fig. 110.—Repaired Casting.

made with soft solder and afterwards blackened by painting with nitric acid in which much copper had been dissolved.

Fig. 110 shows the result of another repair, one which called for rather more care and trouble than the average.

In this case part of the beak of the Ibis was missing from the part marked X. The bronze was much corroded, but the green patina was thin, and so no cleaning process was applied. A casting of the end part of the beak was necessary, but it was doubtful whether the metal of the original part was sufficiently strong to support the weight

Fig. 111.—Broken Lion Headed God.

of the new part if cast solid in bronze. The latter was therefore, cast with a rough surface in aluminium with a central projection to penetrate into the hollow head, and afterwards a coating of copper was electrolytically deposited upon it. The two joining surfaces were filed

flat and the head was filled with plaster of Paris, to secure the projection attached to the beak. Afterwards the added part was painted with ammonia, then lightly with a mixture of methylated spirit, copper carbonate, and shellac, and the result was so satisfactory that the joint was quite hidden, and the new part could not be distinguished from the old.

Another example of a repair made by the author is the small figure of the lion-headed god shown in Fig. 111. When received this object had already been cleaned, but had been broken, one leg being broken off in two parts, whilst the other leg had been broken off some time before and imperfectly soldered on again. The photograph shows it in this state. Fortunately, the two fractures were fresh ones, and the surfaces were preserved, thus fitting together accurately, but the lower part (foot) could not be used again. Therefore, a new foot had to be made, and this was done by filing one to shape out of a piece of antique bronze and fitting to the leg piece. The method of making the joints was as follows :—A hole was drilled in each piece, and also in the body, and an iron pin was fitted so as to support each joint centrally. The leg portion containing the two pins and the new foot are shown in Fig. 112. The cementing medium was a mixture of seccotine and copper carbonate, which makes a very useful green cement for such purposes where the green colour is suitable. In other cases, where objects are black or red in colour, lamp black or venetian red dry paint may be substituted for the copper

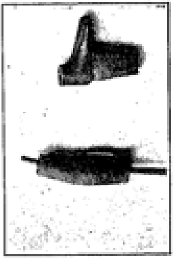

Fig. 112.—Prepared Foot and Pinned Joints.

carbonate. A mixture of seccotine with one of these dry substances sets very hard, but, of course, is not waterproof. As a rule, this is not a drawback, but if a waterproof medium is required, then a thin solution of shellac in methylated spirit can be used with one of the dry powders mentioned.

When the new foot was shaped it had, of course, its metallic lustre, and it was necessary to give it a patina to resemble as closely as possible the original body. This was done by painting with a 10 per cent. solution of liver of sulphur, which produced a black patina, and afterwards a little copper carbonate was dusted over the joints, in order to hide them, and the surplus wiped off. This was quite in harmony with the original, which was of black appearance relieved with small patches of green.

The previously existing joint made with solder was not interfered with, but the crevice was filled up with dark green cement, and thus rendered almost invisible. The result of the repair is shown in Fig. 113. It is interesting to observe that, although a fresh foot has been added, the whole object is still antique.

Although it is desirable to apply imitation antique patinas on parts added to bronzes, this should not be extended to metal stands and wire frames used to support objects in collections. It is done in the Louvre, Paris, but is misleading, because it causes the visitor to think the support is part of the original object.

Sometimes a collector desires to know whether a metal object is bronze or copper. This can generally be inferred from the colour, and a filed part of the object (an unimportant position being, of course, selected) should be compared with the colour of a freshly filed piece of known copper. If, however, the tin content is not large

or the old metal is much corroded, this means of ascertaining is not applicable, and in such cases a fragment should be broken from the object, the oxidised part filed away, and dissolved in a 25 per cent. solution of nitric acid, carefully warming, if necessary, to complete

Fig. 113.—Repaired Lion-Headed God.

solution. If tin is present, it will be left as a white (sometimes greyish) insoluble precipitate at the bottom of the vessel. As tin and antimony are the only two metals likely to leave this precipitate, and antimony is not

present in Egyptian bronzes to any appreciable extent, the test gives a fair guide as to whether a sample is bronze or copper. Sometimes, however, the precipitate may appear grey if gold is present, because nitric acid leaves the latter as a black powder. It may be said that, as a rule, with copper containing more than 2 per cent. of tin, the latter is present as an intentional ingredient, and not as an impurity. This proportion of tin leaves a very noticeable precipitate after attack by nitric acid if a half-gramme sample is taken. As a rule, however, real antique bronzes always contain more than 5 per cent. of tin, and antique copper generally under 1 per cent.

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